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TITLE

OVERVIEW OF SHIPBOARD DATA FUSION AND RESOURCE MANAGEMENT R&D RESULTS AND RATIONALE FOR ITS REAL-TIME IMPLEMENTATION IN THE ASCACT TESTBED

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OVERVIEW OF SHIPBOARD DATA FUSION AND RESOURCE MANAGEMENT R&D RESULTS AND RATIONALE FOR ITS REAL-TIME IMPLEMENTATION IN THE ASCACT TESTBED

by

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Approved by / approuvé par

Chief Scientist / Scientifique en chef

16/4/96

Date

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ABSTRACT

The objective of the ASCACT (Advanced Shipboard Command and Control Technology) project is to improve data processing capability for shipboard Command and Control Information Systems (CCISs) by developing a multiprocessor testbed. The general purpose of the ASCACT testbed is for the integration of high performance Commercial Off-The-Shelf (COTS) products into the shipboard CCIS in order to resolve the envisioned high speed, high throughout, data base intensive applications of the future. The ASCACT testbed will allow investigations to occur on any combination of these requirements. To fulfill the objective of an ongoing task sponsored by the Directorate Maritime Ship Support (DMSS 8), the Defence Research Establishment Valcartier (DREV) is currently providing consulting services in support of the ASCACT project. The content of this document responds to the requirements of Activity 1 of the task. In that respect, the document identifies and describes the R&D work conducted at DREV in the areas of Multi-Sensor Data Fusion (MSDF), Situation and Threat Assessment (STA) and Resource Management (RM) that can potentially be used in the ASCACT testbed. It also discusses the level of effort to port that technology to ASCACT. In addition, an overview of the ASCACT project, a discussion of the context in which the project is conducted, and a description of the ASCACT Integration Working Group mandate and activities are also presented.

RÉSUMÉ

L'objectif du projet TACECN (Technologie avancée du commandement et contrôle naval) est d'améliorer la capacité de traitement des données pour les systèmes d'information du commandement et contrôle (SICC) navals par le développement d'un banc d'essais multiprocesseurs. Le but général du banc d'essais TACECN est l'intégration de produits commerciaux haute performance dans le SICC naval de façon à résoudre les besoins anticipés des futures applications impliquant de grandes vitesses de calcul, de nombreux transferts de données, et à forte intensité en requêtes pour les bases de données. Le banc d'essais TACECN permettra de faire des recherches sur toute combinaison de ces besoins. Pour réaliser l'objectif d'une tâche courante parrainée par le Directeur – soutien aux navires (DSN 8), le Centre de recherches pour la défense, Valcartier (CRDV) fourni présentement des services consultatifs pour appuyer le projet TACECN. Le contenu de ce document répond aux besoins de l'activité 1 de la tâche. En ce sens, le document identifie et décrit le travail de R&D mené au CRDV dans les domaines de la fusion de données provenant de capteurs multiples (FDCM), de l'évaluation de la situation et de la menace (ESM) et de la gestion des resources (GR) et qui pourrait potentiellement être utilisé dans le banc d'essais TACECN. Le niveau d'effort pour transférer cette technologie à TACECN est aussi discuté. De plus, un survol du projet TACECN, une discussion du contexte dans lequel le projet est mené, et une description du mandat et des activitées du groupe de travail sur l'intégration dans TACECN sont aussi présentés.

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EXECUTIVE SUMMARY

It is anticipated that the principal threat to our surface ships in the open ocean and littoral operating scenarios of the future will be from air attacks by sophisticated, fast anti-ship missiles fired from air, surface, subsurface or shore-based platforms, at closely spaced arrival intervals, and by aircraft dropping guided or unguided bombs. These air attacks are characterized by great rapidity (imposing very short reaction time), lethality and multiple simultaneous engagements in a very complex environment.

The approach put forward and developed by the Data Fusion and Resource Management (DFRM) Group at the Defence Research Establishment Valcartier (DREV) to help counter this threat is to increase the Above Water Warfare (AWW) defence capability of Canadian Patrol Frigates (CPFs) through the development of a real-time, semi-automated advisory decision support system. Such a system must continuously take in data from the ship's sensors and other information sources, build an accurate AWW tactical picture as quickly as possible, provide the most likely interpretation of the tactical situation, suggest options to defend the ship using the best possible combination of hardkill/softkill weapons or other defensive means (e.g., suggest an optimal sequence of sensor and weapon allocations) and present fused information and decision support analysis results with the opportunity for the Commanding Officer and AWW team to accept/reject recommended actions/plans in a timely manner, and coordinate and direct execution of these actions/plans.

Such future naval systems, built using a combination of numerical and artificial intelligence technologies, will have severe data and information processing requirements placed upon them. Warships will also have a requirement for a rapid and simple communication medium for the integration of combat system computers. The Advanced Shipboard Command and Control Technology (ASCACT) project, also known as project D6195, has been setup and approved in 1987 with the objective to improve shipboard data processing capability for Command and Control Information Systems (CCIS) by developing an Advanced Development Model (ADM) multiprocessor testbed. The general purpose of the ASCACT testbed is for the integration of high speed Commercial Off-The-Shelf (COTS) products into the shipboard CCIS in order to resolve the envisioned high speed, high throughout, data base intensive applications of the future. The ASCACT testbed will allow investigations to occur on any combination of these requirements.

Project D6195 is managed by the Directorate Maritime Ship Support (DMSS 8). The ASCACT Integration Working Group (AIWG) has been established by both DMSS 8 and DREV to fulfill a jointly identified requirement for a formal information exchange mechanism between the two organizations about R&D issues relevant to ASCACT. Through a task entitled "Capture of the ASCACT Integration Testbed Requirements" and an active participation in the AIWG, the DFRM group is currently providing consulting services in support of the preparation for the Integration Phase. The content of this document responds to the requirements of Activity 1 of the task. In that respect, it identifies and describes the R&D work conducted at DREV in the areas of shipboard Multi-Sensor Data Fusion (MSDF), Situation and Threat Assessment (STA) and Resource Management (RM) that can potentially be used in the ASCACT testbed and it discusses the level of effort to port that technology to ASCACT. In addition, an overview of the ASCACT project, a discussion of the context in which the project is conducted, and a description of the ASCACT Integration Working Group mandate and activities are also presented.

LIST OF ACRONYMS

AAW	Anti-Air Warfare
AAWC	Anti-Air Warfare Commander
ADM	Advanced Development Model
ADM(Mat)	Associate Deputy Minister (Material)
AFCCIS	Air Force Command and Control Information System
AHWG	Ad Hoc Working Group
AI	Artificial Intelligence
AIWG	ASCACT Integration Working Group
APAR	Active Phased Array Radar
AUSCANNZUKUS	Australia Canada New Zealand United Kingdom United States
ASCACT	Advanced Shipboard Command and Control Technology
AWW	Above Water Warfare
CANEWS	Canadian Electronic Warfare System
CASE	Computer-Aided Software Engineering
CASE_ATTI	Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification
C2	Command and Control
C3I	Command, Control, Communications and Intelligence
CCIS	C2 Information System
CCS	C2 System
CFCCOIS	CF Command and Control Operational Information System
CIWS	Close-In Weapon System
COTS	Commercial Off-The-Shelf
CPF	Canadian Patrol Frigate
CPU	Central Processing Unit
CRAD	Chief Research And Development
CRDV	Centre de recherches pour la défense, Valcartier
CRT	Centre de recherches sur les transports
CSTC	Combat Systems Test Center
CSTSF	Combat Systems Test and Support Facility
DCDS	Deputy Chief of Defence Staff
DF	Data Fusion

LIST OF ACRONYMS (cont'd)

DFRM	Data Fusion and Resource Management
DIMPPC	Director Information Management Planning and Program Coordination
DIRAC	Defence Industrial Research Advisory Committee
DIRP	Defence Industrial Research Program
DISO	Defence Information System Organization
DMSS	Directorate Maritime Ship Support
DND	Department of National Defence
DNR	Directorate Naval Requirements
DoD	Department of Defence
DREO	Defence Research Establishment Ottawa
DREV	Defence Research Establishment Valcartier
DSAM	Deputy Scientific Advisor Maritime
DSN	Directeur – soutien aux navires
DSP	Defence Services Program
ECM	Electronic Counter Measures
EMCON	Emission Control
E-O	Electro-Optical
ESM	Electronic Support Measure
ESM	Évaluation de la situation et de la menace
EWCP	Electronic Warfare Control Processor
FDCM	Fusion de données provenant de capteurs multiples
FDDI	Fiber Data Distributed Interface
FY	Fiscal Year
GOTS	Government Off-The-Shelf
GR	Gestion des resources
HCI	Human Computer Interface
HQ	Head Quarter
ID	Identification
IEEE	Institute of Electrical and Electronic Engineers
IFF	Identification of Friend or Foe
IMM	Interacting Multiple-Model

LIST OF ACRONYMS (cont'd)

INTPDS	Integration Phase Project Definition Study
I/O	Input / Output
IR	Infrared
IRAD	Independent R&D
IRST	Infrared Search and Track
ISC	Intelligence and Security Complex
JDL/DFS	Joint Directors of Laboratories Data Fusion Subpanel
JMCIS	Joint Maritime Command Information System
JOTS	Joint Operational Tactical System
JPDA	Joint Probabilistic Data Association
JPDAF	Joint Probabilistic Data Association Filter
KBS	Knowledge-Based System
LAN	Local Area Network
LFIS	Land Forces Information System
LIVEX	LIVe EXercise
MCOIN	Maritime Command Operational Information Network
MDN	Ministère de la défense nationale
MFR	Multi-Function Radar
MHT	Multiple Hypothesis Tracking
MIMD	Multiple-Instruction Multiple-Data
MLC	Missile Launch Controller
MONIME	Management of Organic and Non-organic Information in a Maritime Environment
MRDOG	Maritime R&D Overview Group
MSDF	Multi-Sensor Data Fusion
MTP	Maritime Tactical Picture
NAAWS	NATO Anti-Air Warfare System
NCOT	Naval Combat Operational Trainer
NDHQ	National Defence Head Quarter
NDOC	National Defence Operations Centre
NETE	Naval Engineering Test Establishment
NFR	NATO Frigate Replacement

LIST OF ACRONYMS (cont'd)

NRE	Non-Recurring Engineering
NSERC	Natural Sciences and Engineering Research Council of Canada
NTDS	Naval Tactical Data System
NILE	NATO Improved Link Eleven
NN	Nearest-Neighbor
NRE	Non-Recurring Engineering
NTCS-A	Naval Tactical Command System - Afloat
OGD	Other Government Departments
O-O-D-A	Observe-Orient-Decide-Act
ORTT	Operations Room Team Trainer
OSA	Open Systems Architecture
PCP	Program Change Proposal
PCBSC	Program Control Board Sub-Commitee
PDS	Project Definition Study
PD	Project Director
PM	Project Manager
PMO	Project Management Office
PPP	Program Planning Proposal
PVM	Parallel Virtual Machine
RCMP	Royal Canadian Mounted Police
R&D	Research and Development
RM	Resource Management
RMCC	Royal Military College of Canada
RMS	Resource Management System
RTDDBMS	Real-Time Distributed Data Base Management System
RTE	Run-Time Executive
RTS	Real-Time System
SAM	Surface-to-Air Missile
SARA	Situation Assessment and Resource Allocation
SBN	Single Board Node
SCI/RT	Scalable Coherent Interface for Real-Time
SDB	Serial Data Bus

LIST OF ACRONYMS (cont'd)

SDE	Standard Digital Equipment
SDFP	Sensor Data Fusion Processor
SDTF	Software Development and Test Facility
SDX	Standard Distributed Executive
SHINPADS	Shipboard Integrated Processing and Display System
SICC	Systèmes d'information du commandement et contrôle
SIMD	Single-Instruction Multiple-Data
SOW	Statement Of Work
SRB	Senior Review Board
SRTE	Simulated Real-Time Environment
STA	Situation and Threat Assessment
STIR	Separate Track and Illumination Radar
TA	Threat Assessment
TACECN	Technologie avancée du commandement et contrôle naval
TDS	Task Description Sheet
TEWA	Threat Evaluation and Weapon Assignment
TRUMP	Tribal class Update and Modernization Project
USN	US Navy
VMEbus	Versa Module Euro bus
WANTAP	Wide Area Naval Tactical Picture
WAP	Wide Area Picture
WEM	Weapon Engagement Manager

1.0 INTRODUCTION

It is anticipated that the principal threat to our surface ships in the open ocean and littoral operating scenarios of the future will be from air attacks by sophisticated, fast anti-ship missiles fired from air, surface, subsurface or shore-based platforms, at closely spaced arrival intervals, and by aircraft dropping guided or unguided bombs. These air attacks are characterized by great rapidity (requiring very short reaction time), lethality and multiple simultaneous engagements in a very complex environment (i.e., with friends, foes, neutrals, etc.).

The approach put forward by the Data Fusion and Resource Management (DFRM) Group at the Defence Research Establishment Valcartier (DREV) to help counter this threat is to increase the Above Water Warfare (AWW) defence capability of Canadian Patrol Frigates (CPFs) through the development of a real-time, semi-automated advisory decision support system. Such a system must continuously take in data from the ship's sensors and other information sources, build an accurate AWW tactical picture as quickly as possible, provide the most likely interpretation of the tactical situation, suggest options to defend the ship using the best possible combination of hardkill/softkill weapons or other defensive means (e.g., suggest an optimal sequence of sensor and weapon allocations) and present fused information and decision support analysis results with the opportunity for the Commanding Officer and AWW team to accept/reject recommended actions/plans in a timely manner, and coordinate and direct execution of these actions/plans.

To develop this decision aid system approach, many R&D investigations in the areas of shipboard Multi-Sensor Data Fusion (MSDF), Situation and Threat Assessment (STA) and Resource Management (RM) have been conducted over the last few years by the DFRM group at DREV and its contractors and collaborators (industry and university), analyzing and demonstrating different MSDF/STA/RM approaches, algorithms and techniques for the CPF. These R&D investigations have established a substantial technological basis by addressing a broad range of issues concerning the application of MSDF, STA and RM technologies to the CPF.

Previous work in MSDF/STA/RM clearly indicates that these future naval systems, built using a combination of numerical technologies such as Kalman filters and artificial intelligence technologies such as knowledge-based systems, will have severe data and information processing requirements placed upon them. Warships will also have a requirement for a rapid and simple communication medium for the integration of combat system computers. The Advanced Shipboard Command and Control Technology (ASCACT) project, also known as project D6195, has been setup and approved in 1987 with the objective to improve shipboard data processing capability for Command and Control Information Systems (CCISs) by developing an Advanced Development Model (ADM) multiprocessor testbed. The general purpose of the ASCACT testbed is for the integration of high speed Commercial Off-The-Shelf (COTS) products into the shipboard CCIS in order to resolve the envisioned high speed, high throughout, data base intensive applications of the future. The ASCACT testbed will allow investigations to occur on any combination of these requirements. The ASCACT project, managed by the Directorate Maritime Ship Support (DMSS 8), is divided into four phases (i.e., Real-Time Distributed Data Base Management System (RTDDBMS), Human Computer Interface (HCI) Study, Development of VME SHINPADS Nodes, and Integration).

DREV staff members have been involved in the RTDDBMS Phase of the project as scientific advisors. Through an active participation in the ASCACT Integration Working Group (AIWG), the DFRM group is currently providing consulting services in support of the preparation for the Integration Phase. Due to the increased extent of DREV resources required for the successful realization of the ASCACT testbed, a new task entitled: "Capture of the ASCACT Integration Testbed Requirements" has been defined to provide the required support for the project. This task is conducted by the DFRM group with DMSS 8 as the sponsor.

This document is the first of three to be produced by DREV as deliverables for the task. The contents of this first document respond to the requirements of Activity 1 (i.e., "Identification of DREV's R&D Activities Relevant to ASCACT") as specified in the Task Description Sheet (TDS). In that respect, this document identifies and describes the R&D work conducted at DREV in the areas of MSDF, STA and RM that can potentially be used in the ASCACT testbed and it also discusses the level of effort to port that technology to ASCACT.

A major objective pursued with this document is the production of a single reference document providing all the baseline information for any of the project's participants to get a working knowledge of the past, current and future activities relevant to the project. This document therefore establishes a foundation or a common basis for the activities of the task. Hence, in addition to the presentation of DREV's R&D outcomes, the document also provides an overview of the ASCACT project, a discussion of the context in which the project is conducted, and a description of the AIWG mandate and activities. Indeed, many of the considerations addressed in this document result from the AIWG activities.

Chapter 2.0 describes the ASCACT project and testbed. Based mostly on DMSS 8's internal documentation on naval command and control technology provided to DREV, the aim of the project is given along with a description of the main phases of the project. ASCACT is identified as a major component of a set of tools and activities relevant to the development and/or acquisition of integrated shipboard C2 systems for the CPF. The integration of the non-organic information, which is deemed as essential to the ASCACT testbed, is also discussed. Finally, the matter of DND support for the project is briefly addressed.

The purpose of Chapter 3.0 is to identify and briefly describe the R&D work conducted at DREV in the areas of MSDF, STA and RM. The mission of the DFRM research group is first introduced, along with various definitions (i.e., data fusion, etc.) derived and adopted by the DFRM group to establish the scope of its work. The outputs of the R&D activities of the group are then summarized and discussed for each research area taken individually, followed by some remarks on the investigation of the MSDF/STA/RM integration issue. The discussion of these R&D results also includes some references to current work (in particular, a study for the definition of a conceptual framework for shipboard CCISs and a collaborative project with the industry).

The main motivation behind a real-time, integrated MSDF/STA/RM implementation in the ASCACT testbed are identified and discussed in Chapter 4.0. The specific factors that motivate DREV's use of this testbed are first discussed with respect to each of the main areas of research taken individually (i.e., MSDF, STA and RM). Then the integration aspect is addressed. Finally, the rationale for the selection of an appropriate MSDF/STA/RM integration framework is presented, along with a first high-level cut at its design.

Finally, Chapter 5.0 discusses the ASCACT Integration Working Group that was established by DMSS 8 and DREV to fulfill a jointly identified requirement for a formal information exchange mechanism between the two organizations about R&D issues relevant to ASCACT. The mandate, membership and operations of the group are briefly presented.

The activities leading to the production of this document were performed at DREV between November 1994 and June 1995 under both PSC 12C, Ship Combat System Integration, and task 0111T39A, Capture of the ASCACT Integration Testbed Requirements. Within the new thrust based nomenclature adopted by the CRAD (Chief Research And Development) organization, the continuation of these activities is currently covered under thrust 1.a, Integrated Naval Above Water Warfare and Shipboard Command and Control.

The overall objective of this thrust is to enhance the ship commander's effectiveness in understanding and reacting to the current situation. In that respect, the thrust addresses the development of improved individual shipboard assets as well as their optimal integration and coordinated use for integrated surveillance, ship protection and combat direction. It includes sensors, softkill weapon systems (i.e., countermeasures) and platform-level command and control. Of particular concern is to develop expertise and cost effective solutions in critical areas such as sensor data fusion and the integration of information from non-organic assets (i.e., local and wide area data fusion), situation and threat assessment, the coordination of shipboard surveillance and weapon systems (through resource management), interoperability and computer networking and architecture. The components of this thrust individually constitute critical technology areas for maritime defence capability; collectively they involve the examination of equally critical issues that arise in system integration.

The delivery strategy for thrust 1.a, touching as it does on R&D in a number of technology areas, is multifaceted and includes:

- CRAD in-house R&D in critical aspects of component technology areas,
- access and further development of industrial expertise through R&D contracting,
- technology transfer to industry,

- collaborative R&D partnerships with industry and university,
- international collaboration and information exchange, and
- direct exploitation of new technology coming from the thrust through timely insertion in the fleet, e.g., CPF mid-life upgrade, life-cycle improvements to sensor suites, shipboard processors, navigation and communication equipment.

In applicable areas and where required, design, implementation and test of prototypes leading to proof-of-concept, and further work on component simulators, testbeds or field trials, are pursued via industrial partnership and support. Technology proof-of-concept involves the use of standards and Commercial Off-The-Shelf (COTS) technology, as necessary, so as to optimize flexibility and cost at the deployment stage. This strategy is also a prerequisite for achieving the required operational interoperability with other national and allied systems both ashore and afloat.

With respect to the R&D activities described in this document, DREV provides expertise under thrust 1.a in the areas of command and control information systems, including multi-sensor data fusion, situation and threat assessment, response coordination through resource management, software architectures and real-time, high-performance distributed computing.

2.0 THE ASCACT PROJECT AND TESTBED

This chapter, based mostly on DMSS 8's internal documentation on naval command and control technology provided to DREV, gives a brief description of the Advanced Shipboard Command and Control Technology (ASCACT) project, also known as project D6195, that is managed from within DMSS 8. The aim of the project is given along with a description of the main phases of the project.

This chapter also gives some information on the context in which the ASCACT activity is conducted. In particular, the project is identified as a major component of a set of tools and activities relevant to the development and/or acquisition of integrated shipboard C2 systems for the CPF. A basic concept in ASCACT integration is one of formulating an approach that maximizes flexibility and minimizes cost in an evolutionary approach. This fundamental concept is first introduced in section 2.4, discussing the development in ASCACT of a VMEbus SHINPADS node. Additional details about this evolutionary approach are then given in section 2.6.4, in the context of a discussion of the Engineering Testbed concept proposed by DMSS 8. Finally, the integration of the non-organic information, which is deemed as essential to the ASCACT testbed, and the matter of DND support for the project are both briefly addressed.

2.1 Aim of the ASCACT Project

It is anticipated that future CCISs for the Navy will have severe information processing requirements placed upon them in at least the following areas:

- shipboard sensor data fusion;
- situation and threat assessment;
- naval resource management; and
- real-time tactical data management (e.g., the management of organic and non-organic information in concert with the integration of NTCS-A).

To meet the communication requirements of these advanced functions, it is expected that naval platforms of the Maritime Forces will also have a requirement for a rapid and simple communication medium for the integration of combat system computers. The present SHINPADS serial data bus which provides this function in CPF and TRUMP ships will then need to be improved to accommodate the next generation of 32/64-bit computers now under development and on which these advanced functions will run. This translates into a requirement for a combat system integration medium to meet more stringent control and reaction requirements in the near and long terms.

In this context, the objective of the ASCACT project is to improve shipboard data processing capability for CCIS systems by developing an Advanced Development Model (ADM) multiprocessor testbed. This testbed will be used to investigate the adaptation of advanced commercial data processing and management technology for military applications (i.e., it will allow the development and testing of open systems compliant COTS/GOTS products for potential use on the CPF). In particular, the ADM testbed developed during this project will be used to investigate, integrate, test and evaluate various issues such as:

- future additions to the present SHINPADS system,
- an enhanced SHINPADS node,
- examine methods to ensure compatibility with modern high-performance backplanes (e.g., SCI/RT),
- advanced CCIS concepts such as MSDF/STA/RM,
- CCIS performance evaluation methodology and metrics,
- generation of CPF threat scenarios combined with open and closed-loop stimulation,
- real-time distributed database systems,
- CCIS Human Computer Interface (HCI),
- etc.

As a proof of concept of the ASCACT testbed, an integrated MSDF/STA/RM baseline application will be implemented as a distributed real-time system. The testbed will help to establish its real-time requirements on speed, responsiveness, predictability, timeliness, etc. At the same time, the testbed must also provide a capability to evaluate various measures of effectiveness for this MSDF/STA/RM baseline application.

The ASCACT project is divided into four phases. These are:

Phase 1 - Real-Time Distributed Data Base Management System (RTDDBMS).
Phase 2 - Human Computer Interface (HCI) Study.
Phase 3 - Development of a VMEbus SHINPADS Node.

Phase 4 - Integration.

Each phase will be briefly discussed in the following sections. Note that the RTDDBMS and HCI phases look at discrete aspects of the shipboard CCIS requirements, whereas the Integration phase will not only address the integration of the first two phases, but also the overall architecture of future shipboard CCISs. Note also that the information provided in this chapter is not definitive since the direction of the ASCACT project must continuously be refined in order to reflect the requirements imposed upon the shipboard CCIS from both internal and external sources.

2.2 Real-Time Distributed Data Base Management System (RTDDBMS)

The RTDDBMS phase of ASCACT has been designed to conduct research related to the processing of shipboard tactical data. It is expected that future shipboard CCISs, and the related sensor, MSDF, STA, RM and weapon subsystems, will have challenging database management requirements. As enhanced capabilities to shipboard CCISs are introduced, including the import and export of selected portions of the non-organic picture, tactical databases can only get larger. The problems associated with the management of tactical data are only likely to increase in size and complexity. As the processing power and I/O bandwidth of new high-performance computer technology increase, future designers will likely consider placing even greater demands upon the tactical data processing capability of naval combat systems.

Given these considerations, some major issues investigated during the RTDDBMS phase of ASCACT are:

- managing large transient databases (e.g., radar and ESM contact data, track data, etc.);
- database querying and updating in real-time; and
- geographically-distributed databases.

A contract for the development of the RTDDBMS was awarded in April 1993 to Prior Data Sciences Limited of Kanata, Ont. Their design solution (Fig. 1) maximizes the use of Commercial-Off-the-Shelf (COTS) technology. Central to their design is the Oracle 7™ commercial relational database management product, portions of which are distributed among four high-end Sun SparcStation™ workstations. These workstations are

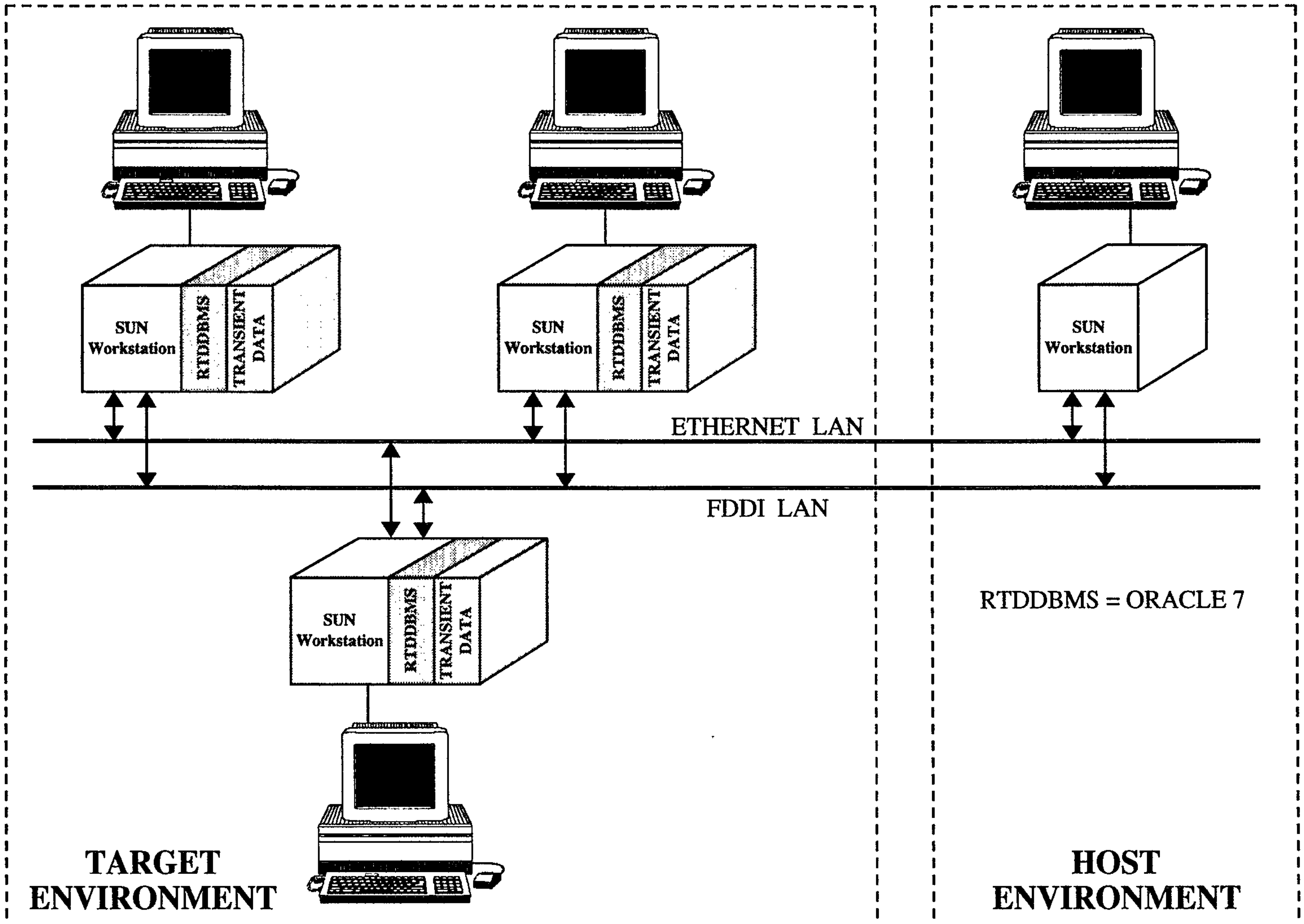

FIGURE 1 - Development environment for the RTDDBMS phase

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interconnected via a FDDI local area network. Tactical data, reflecting the shipboard CCIS track database, is replicated in its entirety on all three nodes of the Target environment (in order to simulate the requirement of data redundancy for a survivable CCIS).

This is a unique solution to the problem of database management for naval shipboard CCISs. Typically, COTS software would be prohibited in such applications due to the real-time constraints on the performance of the overall CCIS. However, with the continuing introduction of increasing powerful hardware platforms such as those being used in this phase of ASCACT, an almost entirely COTS solution is likely to be practical. Indeed, results of the contract with Prior Data Sciences indicate that the use of COTS for naval database management applications is very feasible. The trials have been completed and the delivery to DND of the COTS testbed is scheduled for late 1995.

2.3 Human Computer Interfaces (HCI) Study

In this phase of ASCACT, the HCI as it relates to information systems such as the shipboard CCIS is being studied. Currently, no comprehensive HCI specification tailored specifically to naval systems exists. Amongst other problems, this lack of guidance risks unnecessarily burdening the Navy's limited resources with the repeated development of HCIs, thereby reducing the resources available for developing the other elements of each naval system. Many have voiced a desire for a certain amount of commonalty among the HCI implementations for various elements of the C3I architecture, particularly between the shipboard CCIS and the ashore CCIS.

The HCI phase is to determine the specific requirements of the HCI for combat and marine systems. More specifically, the HCI phase of ASCACT seeks answers to the following questions:

- What hardware and software technologies should be used in the design of a naval information system HCI?
- What elements of an HCI should be tightly specified?
- What elements should be the subject of less restrictive guidelines?

Additionally, the impact of the HCI design on the following areas is taken into account:

- maintenance costs;
- system performance; and,
- training requirements.

The HCI phase comprises two sub-phases: a project definition study and an implementation sub-phase. The project definition study sub-phase is partitioned into five tasks. These are:

Task 1 - Survey of Current Naval HCI.
Task 2 - Report on Naval HCI Requirements.
Task 3 - Survey of HCI Technologies.
Task 4 - Survey of HCI Development Environments.
Task 5 - Project Definition Plan for HCI Implementation Phase.

A contract was awarded in March 1994 to Software Kinetics Ltd. (SKL) for the project definition of HCI prototypes to be used in a study of future HCIs employable with future combat/marine systems. The contract was completed in February 1995. A set of reports has been produced by SKL under this contract. However, it has recently been decided to put the HCI Implementation phase on hold to allow time to take the results of the Naval Combat Operational Trainer (NCOT) project into account. As a result, ASCACT could ultimately become an active participant in this larger scope project, NCOT.

2.4 Development of a VMEbus SHINPADS Node

As it was implied above, the Canadian Navy has a requirement to be able to integrate COTS applications into the shipboard CCS of the CPF class ships. In order to allow the development, testing and integration of COTS/GOTS workstations into the evolving shipboard CCS, a method of connecting these workstations to the SHINPADS Serial Data Bus (SDB) is required. The Versa Module Eurocard (VME) Single Board Node (SBN) developed under the ASCACT project is a means that could fulfill this requirement.

Figure 2 illustrates how future systems utilizing COTS products may be interfaced to the CPF and TRUMP (Tribal class Update and Modernization Project) CCS. The present-day CCS, illustrated on the bottom of Fig. 2, still possesses a significant amount of growth capability and is meeting the current CPF and TRUMP requirements. In the future, performance improvements to the CCS are envisioned to be through high-speed COTS

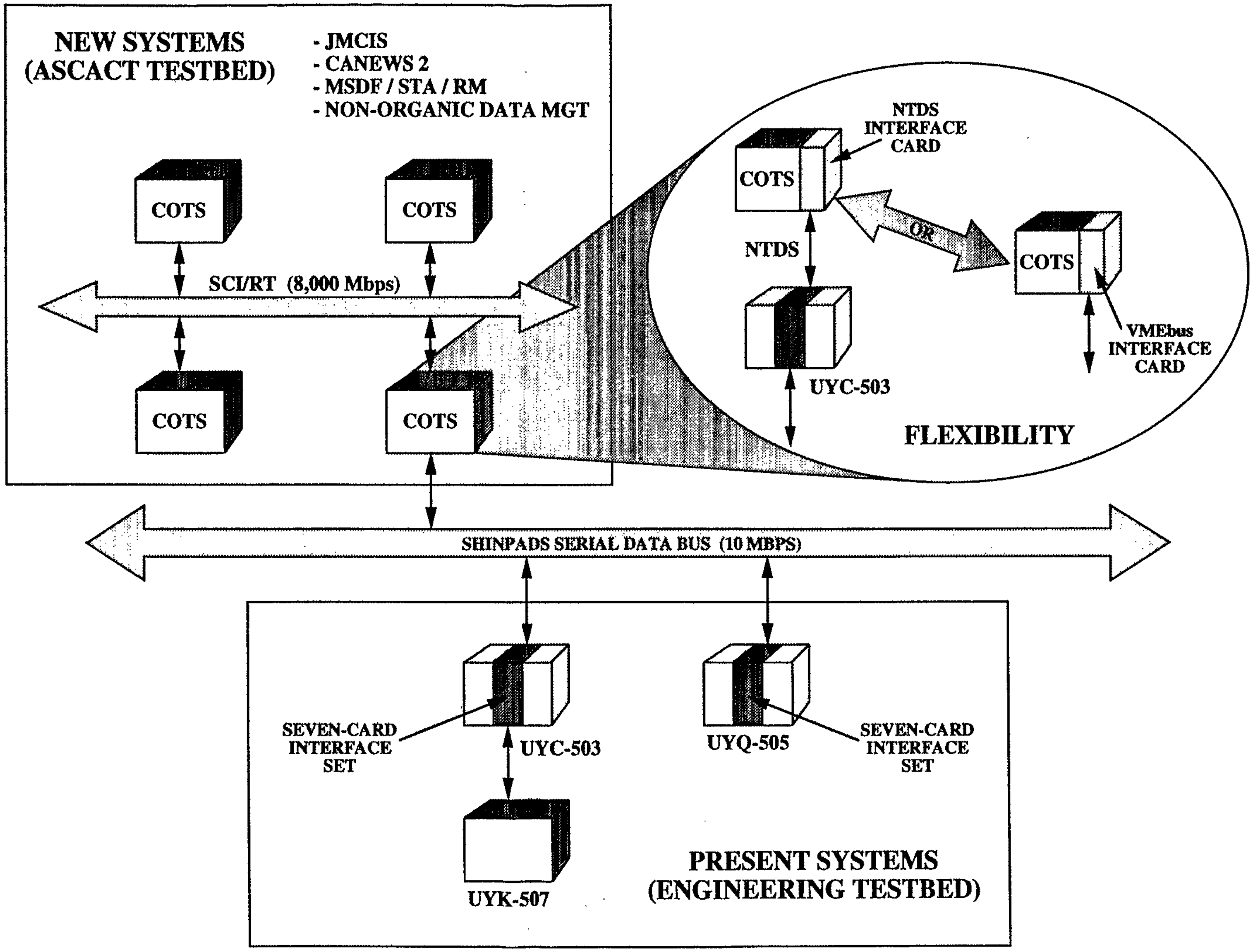

FIGURE 2 - Evolution concept for the shipboard CCIS

products, illustrated on the upper left hand side of Fig. 2. Some possible examples of applications which will utilize this philosophy are Multi-Sensor Data Fusion (MSDF), Joint Maritime Command Information System (JMCIS) integration to CCS, integration of new sensors such as the NATO Improved Link Eleven (NILE), LINK 16, TRUMP ULQ 6/SRD 501 Replacements, etc.

As a result, a means needs to be developed to effectively integrate these systems into today's CCS. As illustrated on the upper right hand side of Fig. 2., there are two suggested methods to give this flexibility. The first method would be to gain access to the SDB via an existing node that has a spare NTDS interface. The second method would be to gain access via a SHINPADS SDB interface card (i.e., the VME SBN) produced for the VMEbus. This bus is a stable, well proven backplane standard which has been in existence for more than a decade. It is an Institute of Electrical and Electronic Engineers (IEEE) standard (IEEE 1014) bus which is an integral part of commercial industry's Open Systems Architecture (OSA) approach for designing and fielding fault-tolerant Real-Time Systems (RTSs). The current VMEbus market is estimated at over $3 Billion annually. Commercial, ruggedized and Mil-Spec VMEbus products are available from a wide variety of vendors in Canada and the United States. The wide vendor support, Open Systems Approach and great flexibility of design, makes VMEbus an ideal choice for the integration of COTS equipment into the shipboard CCS.

Additional details about the evolutionary approach put forward for the shipboard CCIS (Fig. 2) are given in section 2.6.4, discussing the Engineering Testbed concept proposed by DMSS 8.

2.5 Integration

Phase 4 integrates all lessons learned from each activity and then set to work a fully-functional testbed using the hardware of the RTDDBMS (Fig. 1) as the core.

The Integration phase of ASCACT is scheduled to commence with a Project Definition Study (PDS) sub-phase early in 1996, followed immediately by an implementation sub-phase. The purpose of the PDS sub-phase will be to refine the detailed engineering approach required to meet the goal of demonstrating the evolutionary path to future CCISs. More precisely, the PDS will provide the complete costing and recommended implementations and also provide the basis for the SOW for the implementation sub-phase.

A detailed look at the integration phase is thus somewhat premature at this moment. Nevertheless, based on the work accomplished so far by the ASCACT Integration Working Group (see Chapter 5.0), the remainder of this chapter gives some information on the context in which this phase will be conducted and identifies some of the factors that must be taken into account for the ASCACT project Integration Phase.

2.6 CPF CCIS Development Philosophy

The scope of the issues raised within the many R&D activities related to the potential upgrades of the CPF CCIS is very broad and far-reaching. For example, they touch on complex problems in real-time systems design that require extensive exploratory and empirical analyses, as well as studies that range from the evaluation of theoretical concepts (using very simple computer simulations supporting rigorous mathematical analyses) all the way to the actual testing of prototypes during live military exercises (i.e., live ship trials). Hence, part of the overall shipboard CCIS analysis, design, development and evaluation process involves the decision regarding the most appropriate approach or means that will be used for conducting these R&D activities. A characterization of this broad spectrum of possible tools and approaches is shown in Fig. 3. Generally, as is depicted in Fig. 3, there are tradeoffs in selecting one approach over the other. The most obvious one is probably the level of operational realism obtained versus the costs.

The ultimate test to evaluate the military value of a CCIS prototype would be to use it in live military exercises. Such an environment provides reasonably high fidelity operational conditions since the real-world physics, human, equipment and tactics/doctrine can be fully taken into account. However, there are drawbacks to this approach. The system designers typically cannot have full control of the events, and it is difficult to collect the relevant data. For example, precise truth data that are needed for MSDF performance evaluation can be hard to obtain in real-world tests; these are however readily available in computer simulations. The latter typically constitutes very controlled research environments that offer a high level of convenience and flexibility at low cost. Unfortunately, digital simulations cannot always adequately represent complex real-world phenomena and human behavior. Specialized field data collection campaigns can be a good compromise between

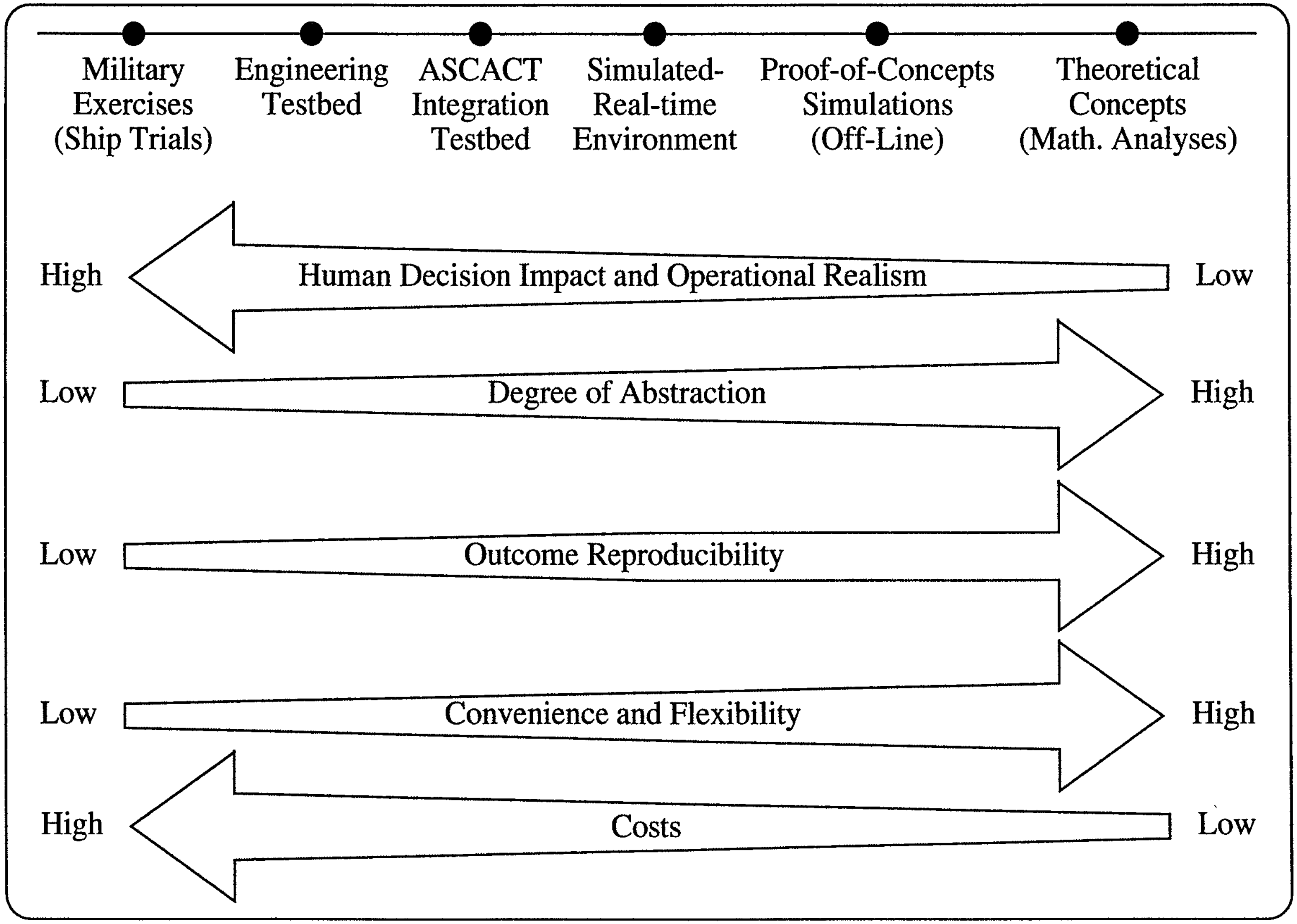

FIGURE 3 - Tradeoffs in analysis / modeling / evaluation approaches for shipboard CCIS

these two extremes. Indeed, this approach is often used to validate computer simulations. However, such trial activities can rapidly become very costly.

Given the broad scope of the issues raised in the enhancement activities put forward for the CPF CCIS, the ASCACT Integration Working Group (see Chapter 5.0) has been quick to realize that no single tool or activity will be sufficient to provide DND with all the required answers. Hence, the R&D environment for the CPF CCIS must rather provide a compatible set of tools and testbeds starting with the DREV testbeds (e.g., the CASE_ATTI, the AAW Simulator, the SRTE, etc.) for basic proof-of-concept research, the ASCACT testbed for research and development, some combination of ASCACT and a shore based SHINPADS bus system (CSTC, SDTF or the Engineering testbed being proposed by DMSS 8) for advanced development, and the shipboard system for user feedback and trials. Figure 4 shows the expected tools/activities loop for the scientists, engineers and operators involved in the development and/or acquisition of integrated shipboard C2 systems for the CPF. This loop is based on current activities conducted by both DREV and DMSS 8, and those planned for the short to medium term future.

The R&D process for the CPF CCIS will undoubtedly require several iterations in the tools/activities loop of Fig. 4, where the results of one iteration lead to refinements, extensions and improvements in the next iteration. It is also evident that progress will both impact and be impacted by naval requirements (i.e., the customer must be kept involved during this iterative process) and that this interaction may subsequently even help in shaping naval doctrine. As such, this will require work both inside and outside the immediate scope of the ASCACT project. The following sub-sections give some information on the main components of the tools/activities loop.

2.6.1 Study of Shipboard CCIS Theoretical Concepts

In the past few years, a lot of research effort within the technology base program of the CCIS Division at DREV has been directed towards the automation of C2 processes for managing the information and allocating the resources by which the naval commander can exercise command and control in actual and future Above Water Warfare (AWW) scenarios. From this work, three critical issues can be put in perspective for the evolution of shipboard CCIS: sensor data fusion, situation and threat assessment, and resource management. Chapter 3.0 discusses this R&D work being conducted at DREV and briefly

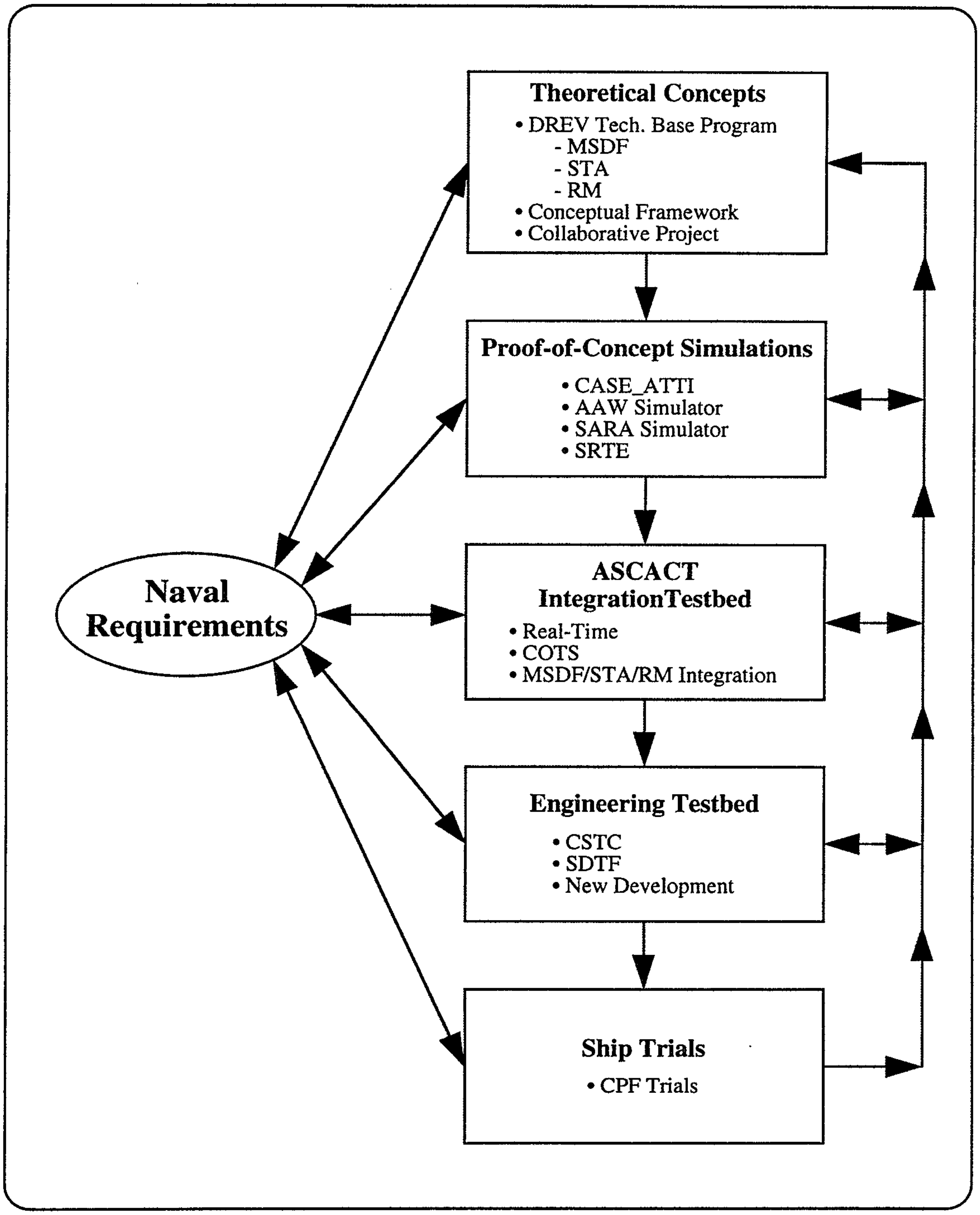

FIGURE 4 - Tools/activities loop for the scientists, engineers and operators involved in the development or acquisition of integrated shipboard CCIS for the CPF

summarizes the main results that have been obtained so far in the areas of MSDF, STA and RM. As part of the current efforts, the conceptual framework activity and a collaborative project with the industry are also described in Chap. 3.0.

2.6.2 Proof-of-Concept Simulation Tools

The extremely limited availability of trial data to support algorithm development and MSDF/STA/RM system prototypes represents a serious detriment to the Canadian R&D community. Many research programs whose focus is on MSDF, STA or RM algorithm analysis and development cannot afford to incur additional costs of data collection for the purpose of demonstrating algorithms with real data. Alternatives to this situation include artificially synthesizing appropriate data from trial data collected under non-standard conditions (not easy to do in a convincing manner), or to employ high-fidelity simulators. This last option has been retained for the MSDF, STA and RM projects at DREV since, most of the time, representative simulated data may be sufficient to verify or validate MSDF/STA/RM concepts.

2.6.2.1 CASE_ATTI

Reference 1 presents an overview of the CASE_ATTI (Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification) algorithm-level simulation testbed that has been developed by DREV to support the research in MSDF. CASE_ATTI provides a highly modular, structured and flexible hardware/software environment necessary to study and compare various advanced MSDF concepts and schemes in order to demonstrate their applicability, feasibility and performance. Reference 1 also discusses how CASE_ATTI is currently being used to support the development and evaluation of advanced sensor data fusion concepts in the context of the CPF.

2.6.2.2 AAW Simulator

A multiple ship Anti-Air Warfare (AAW) Simulator has also been developed by DREV for studying the decision-making of the knowledge-based Threat Evaluation and Weapon Assignment (TEWA) process for a ship that is attacked by anti-ship missiles. The twenty modeled entities of the AAW Simulator were designed according to the specifications of Refs. 2-4 and coded in SMALLTALK 80. Acceptance tests for these entities are currently being performed on the simulator.

2.6.2.3 SARA

Reference 5 presents the design of a flexible, object-oriented, generic TEWA concept demonstrator, known as the Situation Assessment and Resource Allocation (SARA) tool, that has been developed in-house at DREV. Easily adaptable and expandable, SARA is well-suited to investigate concepts, models and algorithms relevant to situation assessment and resource allocation in the naval AAW context.

2.6.2.4 SRTE

The CASE_ATTI, AAW Simulator and SARA tools mentioned above are non-real-time proof-of-concept simulation environments. A separate means is thus required to investigate the real-time aspects of the CCIS components proposed for the future.

The evaluation of the real-time performance of an integrated MSDF/STA/RM system can be done partially by analytical methods (e.g., queuing theory). There are also various simulation and monitoring tools (e.g., Network II.5™, NetMetrix™, etc.) that could be used. However, the option of developing a Simulated-Real-Time Environment (SRTE) tool that would provide the best means to perform non-intrusive, repeatable performance monitoring at the instruction level of a real-time application is currently under investigation (see section 3.7.1).

The proposed SRTE tool would also provide a means to investigate MSDF, STA and RM jointly in an integrated real-time system, whereas the CASE_ATTI, AAW Simulator and SARA tools only address these components individually.

2.6.2.5 Simulation Tools Compatibility

The CASE_ATTI, AAW Simulator and SRTE tools are further discussed below in Chapter 3.0. Up to now, the various research tools which DREV has developed and utilized do not operate well together nor with the proposed ASCACT testbed. The level of effort to integrate portions of these research tools into the ASCACT testbed needs to be evaluated. This will be done as part of the ASCACT Integration Working Group activities. In the future, it is desirable that DREV research performed on proof-of-concept simulations be conducive to portability to the ASCACT testbed with minimal Non-Recurring Engineering (NRE).

2.6.3 ASCACT Integration Testbed

The CCIS integration testbed based on COTS technology to be developed under the ASCACT project has already been introduced above in this chapter. The main features that characterizes this testbed in the CPF tools/activities loop are the real-time aspect and the study of MSDF, STA, RM and other C2 processes jointly in an integrated fashion. A preliminary definition of an integration framework for this testbed is discussed below in Chapter 4.0.

2.6.4 Engineering Testbed for Combat System Upgrades

As discussed in the previous sections, future shipboard CCISs, encompassing MSDF, STA, RM and other C2 applications, could be characterized by high to extremely-high CPU demands and processor interconnect bandwidth requirements. Given the dynamic nature of these requirements, it is essential that the architecture of future CCIS be extremely flexible. It is also assumed that cost will be an overriding concern in almost all implementation decisions. In this context, designing the future shipboard CCIS architecture as an evolution of the present architecture would allow us the flexibility of an evolutionary, incremental upgrade of capability as money becomes available. The Engineering Testbed discussed below is of paramount importance to this evolutionary approach.

2.6.4.1 Current CPF CCIS Architecture

Present systems onboard CPFs are based on Standard Digital Equipment (SDE) such as the UYC-503 node, the UYK-507 processor, the UYQ-505 combined node and processor, and the SHINPADS Serial Data Bus (SDB). The CPF CCIS architecture is distributed, with individual components communicating with each other over the SDB. This SDB, though equal in raw speed (bandwidth) to that of modest LAN standards such as Ethernet at 10 Mbps, is a sophisticated multiple-redundant, fault-tolerant, real-time processor interconnect. Its primary purpose is not as much the transfer of large volumes of data from processor to processor, but the orderly control of the many attached SDE processors. Indeed, it is estimated that the SDB is only loaded to approximately 10-15% of its modest bandwidth.

2.6.4.2 Engineering Testbed Concept

Given the current CCIS architecture described above, and keeping in mind the rationale for an evolutionary approach to any CPF enhancement, what is needed to support CPF combat system upgrades is an R&D environment that allows for:

- the testing of integration techniques for COTS hardware/software;
- the integration of RTDDBMS and other ASCACT products;
- the integration of future systems (e.g., AAW upgrade, WANTAP, MSDF/STA/RM, etc.);
- technology upgrade for displays, processors and peripherals.

Taking these considerations into account, the concept of an Engineering Testbed has been proposed by DMSS 8. The incremental approach for the shipboard CCIS enhancement, including this concept of an Engineering Testbed, is shown in Fig. 2.

To help meet their demanding requirements on the CPF data processing capability, the new C2 component systems would be integrated by adding clusters of computers (such as the cluster developed as part of the ASCACT integration testbed) to the current architecture. In terms of high data-rate transfers, it is expected that the SHINPADS SDB could not have the reserve bandwidth in order to accommodate these future systems' requirements. In spite of this however, the bandwidth of the SDB is not a problem. As previously mentioned, the SDB has been designed as a control bus, and should be retained for this purpose in future shipboard CCISs. This approach has the concomitant advantage of cost reduction since strip-out and replacement of the SDB would not be anticipated as a requirement at CPF mid-life. High-bandwidth communications within each cluster would presumably be handled by some other interconnect such as the Scalable Coherent Interface for Real-Time (SCI/RT) applications which is expected to be capable of 8,000 Mbps. A simple connection to the SDB would then allow these clusters to be monitored or controlled in much the same way as any sensor or weapon system is presently controlled via the SDB.

The connection of new systems to the SDB would be either through any spare NTDS port on existing nodes, or via a developed commercial node card such as the VMEbus node card considered in Phase 3 of ASCACT. As new systems are injected, the

CCIS system would evolve in a carefully planned manner. This corresponds to an evolutionary concept as opposed to a revolutionary concept.

Among the concrete benefits that DND would gain from the availability of the proposed Engineering Testbed are the following:

- DND would be in a position to insert new technology on the ships (schedule reduction);
- it would allow for the development and testing of new operational concepts for the combat system (reduction of the technical risk);
- it would allow the preparation of valid and realistic performance specifications for the combat system (reduction of the technical risk);
- it would allow for a systematic approach to making changes to the combat system (all R&D projects could use the Engineering Testbed);
- it would allow for the testing of different options, algorithms, etc. (e.g., MSDF, STA, RM),
- it could be used for overflow software maintenance (e.g., for the maintenance of the Standard Distributed Executive (SDX) software module of the CPF); and
- a near term use could be the integration of JMCIS, EWCP, AAW.

The Engineering Testbed would be set up to run Halifax class software systems.

2.6.4.3 Engineering Testbed Development

The proposed Engineering Testbed, shown in Fig. 5, must be based on the present SHINPADS SDB, and incorporate enough of the present SDE to effectively demonstrate compatibility of new systems with the present architecture. This would prove the evolutionary approach to upgrading shipboard CCIS capabilities. The two CPF facilities listed below meet these requirements:

- CSTC This is the Combat Systems Test Center facility currently located in Halifax. It was previously called CSTSF (Combat Systems Test and Support Facility) before its move from Montreal (Loral Canada) to Halifax.

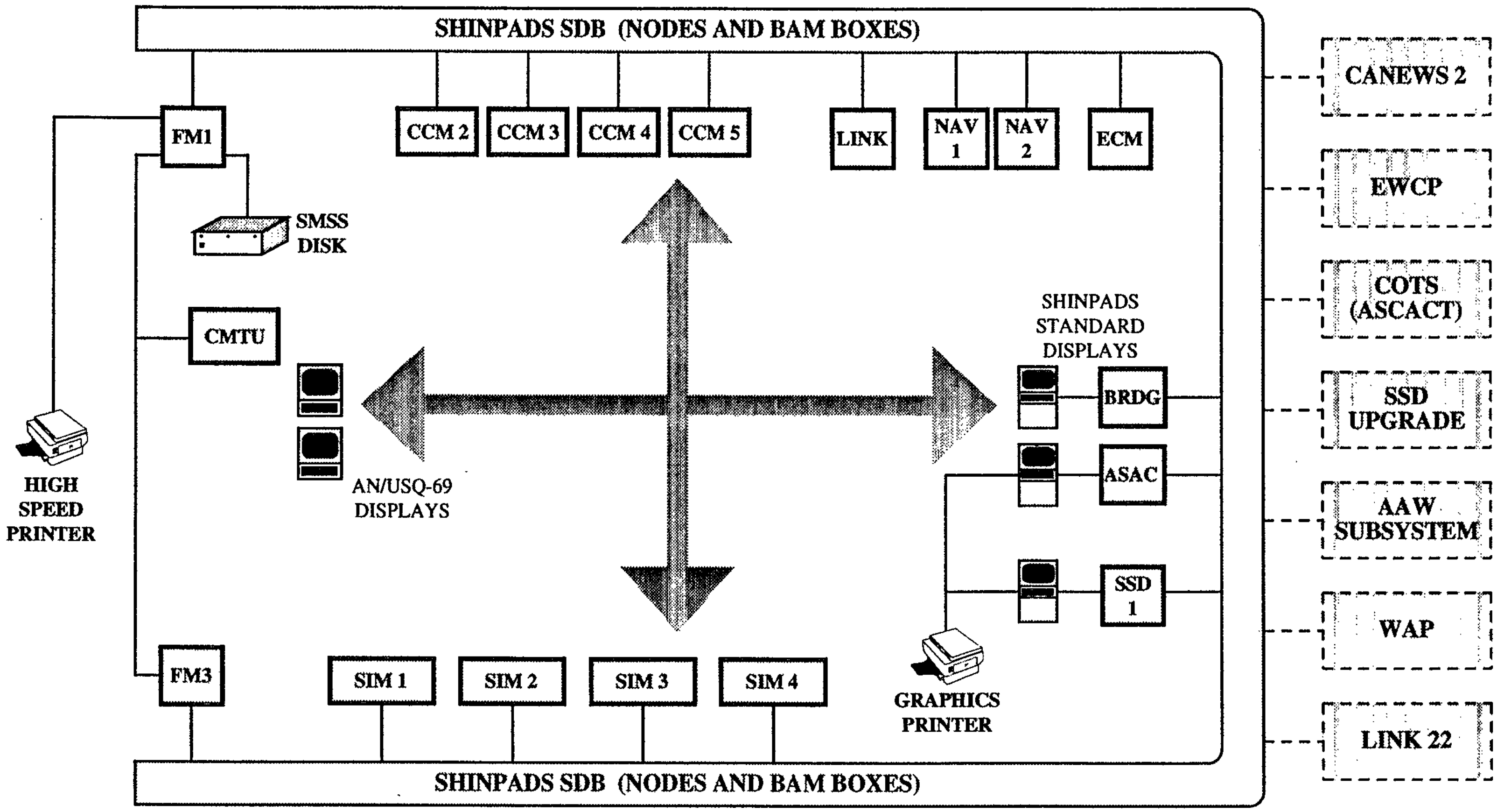

FIGURE 5 - Engineering testbed proposed by DMCS 7

- SDTF This is the Software Development and Test Facility previously located in Montreal (Loral Canada). It has also been moved to Halifax.

However, these facilities are being used for training and maintenance almost 24 hours/day. Clearly, the R&D oriented Engineering Testbed cannot be shared with training or normal system maintenance in steady state. DREV and DMSS also need control of the Engineering Testbed for major system changes.

Hence new developments are required to provide the Engineering Testbed to the R&D community. However, although the rationale for the Engineering Testbed is becoming well established, its funding and development still need to be approved.

Obviously, a cost effective approach is needed. As an initial step toward a potential solution, DMSS 8 is currently investigating the repatriation of the four-node system testbed currently located at Loral Canada's facilities in Ottawa. A task has been issued to Loral Canada to prepare a B-Class cost estimate for upgrading the constituent SDE of this system from a UYK-502 architecture to a UYK-507/UYQ-505 processor suite in order to reflect the baseline system architecture of CPFs. This task should be completed by August 1996. DMSS 8 is also investigating the option of a cost sharing with Loral Canada to develop the Engineering Testbed. Talks are in the preparation stage and a significant amount of work is still required to bring it to fruition. Assessing the timeline for this development (assuming the shared-cost option is acceptable), it is envisioned to have the Engineering Testbed in place by FY 97.

As a final remark, it is expected that the Engineering Testbed could eventually reside at DREV, NETE or at a contractor site.

2.6.5 CPF Trials

Given the level of realism that they provide for system design and evaluation, high-quality ship trials are a goal that the Canadian R&D community should be seeking. With respect to MSDF R&D for example, there is an urgent need for data sets from real sensors and targets, even though such sensor-target pairs may only be representative for a specific variety of applications. To date, however, very little calibrated and simultaneously collected data on targets of interest exists. This is especially true for the case of dissimilar sensors.

Only a few organizations, almost exclusively located in the US or Europe, have invested in the collection of such trial data. Given various political factors and the cost of such collection operations, these data are usually very sensitive and typically become (appropriately) proprietary. As a result, most of the time MSDF designers must content themselves with trial data that have only a limited relevance to MSDF. One should note that the situation is similar with respect to the other C2 processes.

Despite the huge amount of efforts (human resources, money, etc.) that the setup and performance of high-quality ship trials represents, these trials constitute the most important component of the CPF CCIS tools/activities loop since they represent the ultimate means by which the military customer can evaluate a prototype and provide feedback to the scientific and engineering communities, ensuring that the final product does address the identified needs of the Forces.

2.7 Integration of Non-Organic Information

The ASCACT project (and equivalently its associated integration testbed) has been conceived to address data processing R&D issues relevant to the tactical CCIS of CPFs. Moreover, the emphasis for the first baseline application to be implemented and investigated with the ASCACT testbed is currently given to the management of the organic information for the CPF (i.e., MSDF/STA/RM based on CPF organic resources). However, the ASCACT project team also considers other aspects (e.g., the integration of the non-organic information, the strategic issues) associated with the global C2 architecture put forward for the Forces.

Some naval C3I architecture requirements, such as the MCOIN 3 and NTCS-A systems, are themselves interrelated, and in turn drive the external interface requirements of the shipboard CCIS. Hence, R&D for the shipboard CCIS must take into account the issues related to the various CCISs ashore. In particular, in terms of the future expansion of the ASCACT testbed, the hooks to evolve from a tactical only system to a system that also operates on strategic information must be identified. For example, the potential input/output requirements for the MSDF/STA/RM baseline application running on the testbed must be identified.

The next two sections briefly discuss two major activities that are closely monitored by the ASCACT team in order to ensure that the ASCACT testbed will remain in line with progress made during the CF global C2 architecture evolution.

2.7.1 The Management of Organic and Non-Organic Information in the Maritime Environment[1]

Modern warships carry a multitude of types of equipment including radar, ESM, and E-O which provide information allowing the commander at sea to gain a level of situational awareness. This type of information can be defined as organic information, as it is controlled and collected by assets under his direct control. This organic information is sufficiently timely and accurate to be used in real-time, responsive systems. Consequently, it can be used to produce a local Tactical Picture which supports all of the commander's activities at sea.

The commander ashore equally has the need to obtain information on a more global scale. Shore-based systems have been developed to collect, store and disseminate a vast amount of information in an attempt to provide some sort of global situational awareness. Some of this information is also of considerable interest to the sea-going commander. However, this information is collected by agents not under his direct control. Such a source of information is referred to as "non-organic". It brings to the sea-going commander a new problem of how to integrate this information with his own organic information. Within the AUSCANNZUKUS organization, this has led to the term "Management of Organic and Non-organic Information in the Maritime Environment" (MONIME).

The advancement of communications capacity and the development of data transfer technologies inevitably have made it possible to provide the commander at sea with access to a new and increasing amount of non-organic information available from world-wide sensors. The first truly automated attempt at providing the commander at sea with access to non-organic information was the USN Joint Operational Tactical System (JOTS). JOTS can be seen as one solution to managing non-organic information. When first conceived it was a solution to providing access to a very large database and displaying the information

[1] The information in this section has been extracted from: AUS-CAN-NZ-UK-US Naval C3 Group / C2 Committee, "Handbook 5: The Management of Organic and Non-Organic Information in the Maritime Environment", DRAFT, Issue 1.1, 17 March 1995, UNCLASSIFIED.

in an easily understood format. The user requirement was loosely stated and the requirement to integrate organic information was not identified.

Non-organic information has characteristics which make it quite different from organic information. It is less timely, reduced in accuracy, differently structured and has differing identification confidence levels. For these reasons, it can not easily be integrated into the existing organic "Tactical" picture which traditionally has been used with confidence to employ force or unit weapons and sensors. The inclusion of non-organic information into the organic "Tactical" picture had a propensity to confuse and clutter the original picture. As a result, the non-organic information was displayed separately and primarily used as a planning aid over a larger geographic area. From this arose the concept of the Wide Area Picture (WAP). This picture becomes even more useful when shared by a number of naval forces over a large area and is a vital command decision aid. For this to occur there needs to be an assurance of a common Maritime Tactical Picture (MTP). To ensure its timeliness, the MTP must be exchangeable via an automated information exchange system similar to data links which have traditionally conveyed the organic tactical picture.

Currently, this stand alone display presently evolving within the USN under the Joint Maritime Command Information System (JMCIS) concept, has become one solution to MONIME. There have been considerable advances in timeliness, quality and capacity since JOTS was first fielded. Despite advances in software, and the hardware displaying information to the user, there has been no change in the fundamental method of MONIME.

In 1993, the AUSCANNZUKUS Supervisory Board commissioned an Ad Hoc Working Group (AHWG) to investigate MONIME. The AHWG evolved a strategy of using simulation, LIVEX, and analysis techniques to quantify the effectiveness of the management processes. Much information has been determined from these efforts and a document, Handbook 5, has been created to collate that work. Handbook 5 seeks to describe the need for, use and management of the MTP and where possible provide policy and standards for operations, and to lay down the guidelines that will promote Allied interoperability. The Handbook is reviewed annually and is intended to be a living, user friendly document. The potential users of Handbook 5 may include those writing Operational Requirements, Procurement Agencies, Research and Development Agencies, and Fleet Commanders. It addresses technical and procedural details leading to the acquisition of new systems which are interoperable. It seeks to promote the rapid introduction of new technology to produce an increasingly better tactical picture without the traditional procurement delays.

2.7.2 National Level Command and Surveillance R&D Activities[2]

Many aspects concerning the development of the global C2 architecture proposed for the Forces are addressed by the CRAD organization under the Thrust 5.a entitled: National Level Command and Surveillance. This thrust deals with national-level C2 functions (which are by nature joint and often combined) and the associated strategic, wide-area surveillance sensor systems (radar, electro-optics, underwater acoustics and electromagnetic). This includes theater level activities in which the CF is deployed to other areas in the world. The thrust will integrate sensor information from the various sources available (Canadian military, allies and non-military) to form a joint intelligence picture and to enable commanders and staff to monitor the overall operational situation. The system needed to support such a concept must provide a high level of information sharing through automated interoperability between the various force-level strategic C2 systems (MCOIN3 (Maritime Command Operational Information, Mark 3), AFCCIS (Air Force CCIS)), their interaction with CFCCOIS (CF Command and Control Operational Information System) and more broadly with Other Government Departments (OGDs) and allies. Links to more tactical systems such as LFIS are also considered. Continental (NORAD) coordination and support for contingency or deployed operations in a global context are key aspects of this thrust.

The DCDS has recently directed that the implementation of an effective CF C2 system be given high staffing priority. The initial task is to upgrade the National Defence Operations Center (NDOC) automated systems and to explore and propose solutions to long-standing deficiencies. Furthermore, in response to the 1994 White Paper on Defence, the Forces Commands will be centralized in NDHQ (Ottawa) and will require direct interaction with NDOC.

In parallel with this effort, the Navy has plans to develop a coordinated shore and shipboard command, control, communications and intelligence (C3I) system to enable all

[2] The information in this section has been extracted from: Otis, G. et al, "Thrust 5.a – National Level Command and Surveillance", Preliminary Thrust Business Plan (5 years), DREV, 2 May 1995, UNCLASSIFIED.

naval shore HQs to automatically collect, display, evaluate and disseminate information in support of a wide area or fleet level picture. The proposed system will also be required to link and interact with the Canadian Maritime Network (CanMarNet) for coordinated missions with OGDs (Coast Guard, Fisheries and Oceans, RCMP) for law enforcement, fishing zone surveillance, etc. CanMarNet will permit departments with maritime interests to participate in the development and use of the consolidated surface picture on a 24/7 basis. DND input will be provided from MCOIN3.

In the surveillance sensor area, the Maritime R&D Overview Group (MRDOG) identified Strategic Surveillance Systems as a high priority requirement in its most recent Way-ahead Paper. The surface coverage can be provided by HF radars in the inner coastal zone, which can be complemented in the middle and outer zones by fixed or deployable acoustic sensor systems and by bottom-mounted electromagnetic sensor arrays in strategic choke points.

The thrust will support the common-core technologies efforts (standardization and interoperability) pursued by DIMPPC, as mandated by DISO and the DCDS. The thrust also provides direct support to CF procurement projects such as ISX (Intelligence and Security Complex - G 1671), MCOIN 3 (Maritime Command Operational Information, Mark 3 - M 1772), CFCCOIS (CF Command and Control Operational Information System - G 2469), etc.

2.8 DND Support for the ASCACT Project

The Program Planning Proposal (PPP) for D6195 was approved by ADM(Mat) in February 1987 and entered into the Defence Services Program (DSP) as "D" capital. The Program Change Proposal (PCP) was submitted and approved by the Program Control Board Sub-Committee (PCBSC) in October 1990 and by the Minister in December 1990. Changes in scope for the D6195 project were sought and gained with Senior Review Board (SRB) approval in June 1995, which still remain valid today.

The support for this project comes from DNR, DSAM and DMSS which are all members of the SRB. Command and Control is the number one priority research issue as it stands now, as specified by the Commander MARCOM. Given the priority that the maritime community places upon C3I, the ASCACT project can be viewed as extremely desirable.

3.0 R&D RESULTS ON SHIPBOARD C2 SYSTEMS INTEGRATION

In the past few years, a lot of effort within the CCIS Division at DREV has been directed towards the automation of C2 processes for managing the information and allocating the resources by which the naval commander can exercise command and control in actual and future Above Water Warfare (AWW) scenarios. Figure 6 shows an appropriate conceptual framework describing the C2 process in the context of a single naval platform (or single ship). This framework puts in perspective three critical processes for the evolution of naval C2: Multi-Sensor Data Fusion (MSDF), Situation and Threat Assessment (STA) and Resource Management (RM). The purpose of this chapter is to identify and briefly describe the R&D work conducted at DREV in these critical fields that can potentially be used in the ASCACT testbed.

A definition is first given of the mission of the Data Fusion and Resource Management (DFRM) research group at DREV. Mostly based on the work conducted by the U.S. Joint Directors of Laboratories Data Fusion Subpanel (JDL/DFS), various definitions (i.e., data fusion, sensor data fusion, situation assessment, threat assessment and resource management) derived and adopted by the DFRM group are also given.

The many R&D results of the activities of the group in the fields of MSDF, STA and RM are then summarized and discussed for each area individually, followed by some remarks on the investigation of the MSDF/STA/RM integration issue. The discussion of these R&D results also includes some references to current work. In that respect, the conceptual framework study and the collaborative project with the industry represent two new activities, each one deserving a separate discussion. Concerning the latter activity, DREV has been asked to integrate its work in MSDF, STA and RM to allow for use in the ASCACT testbed. In order to properly conduct this integration, DREV is currently assessing forming a partnership with the industry for, among other things, the development of a research tool (i.e., a Simulated-Real-Time Environment (SRTE)). This tool will allow integrated MSDF/STA/RM research to be performed, thus assessing its applicability prior to porting to the ASCACT testbed (see section 2.6.2.4).

This chapter only summarily discusses the level of effort required to port the MSDF/STA/RM technology R&D results from DREV's work to ASCACT. A significant amount of work still remains to be done on identifying which areas of DREV's available

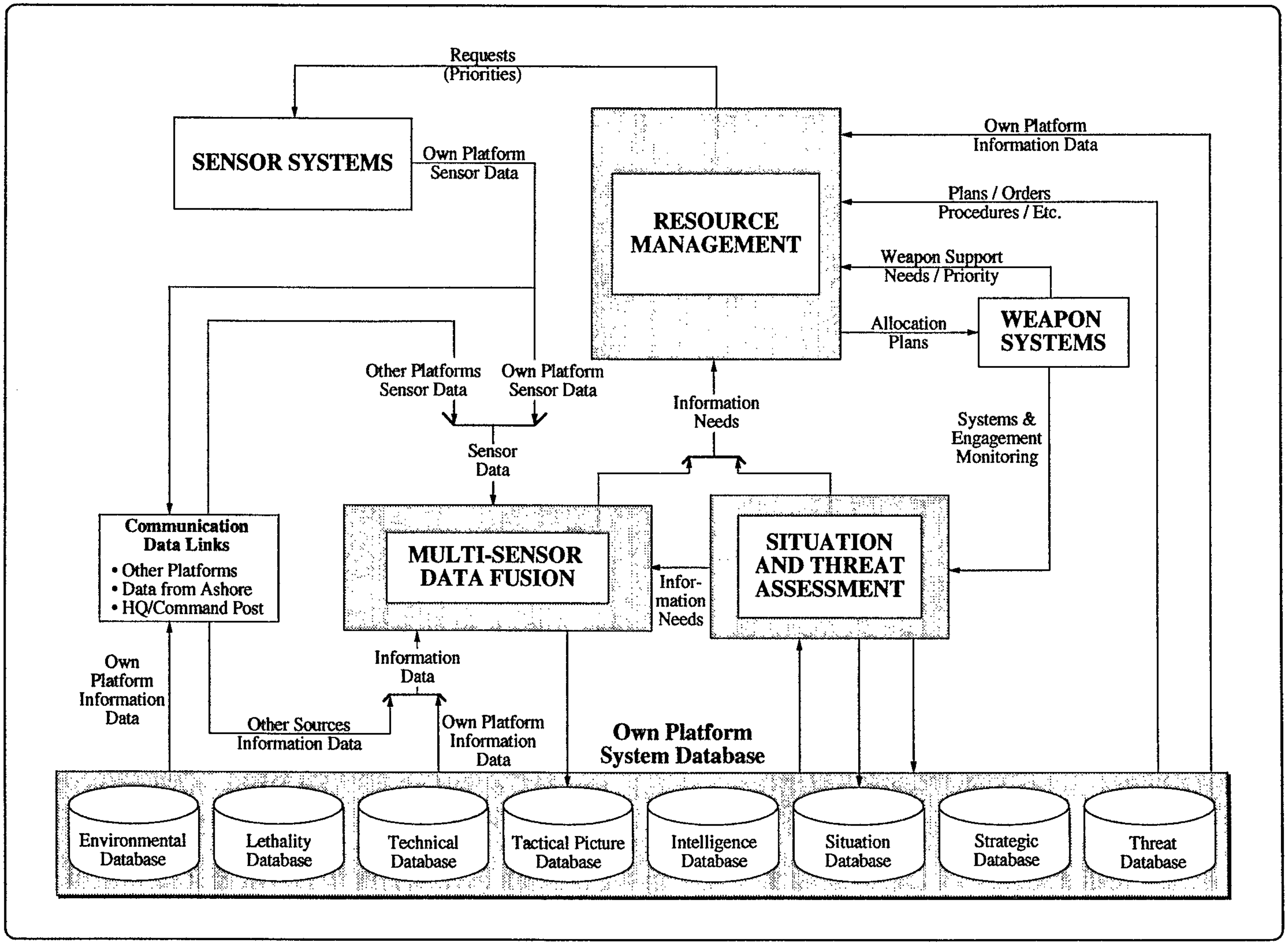

FIGURE 6 - Naval command and control conceptual framework

results and proposed work should be implemented and further investigated within the initial version of the ASCACT testbed. Recommendations must be made on which areas best meet ASCACT requirements for implementation, while carefully considering the risk of advancing with undeveloped theories and applications. The areas of study should possess high potential for success (i.e., follow a medium risk approach) and be able to be ported to a shipboard application for operator assessment (although the timeline for this port remains to be defined). As much as possible ideally, consideration should also be given to international work which has been accomplished in these fields to ensure duplication of effort is minimized (i.e., do other countries have algorithms, development models which could be used?). These considerations mentioned above fall beyond the scope of this document and will be addressed in a subsequent report to be delivered for the task.

3.1 The Data Fusion and Resource Management Group

The R&D activities in the Data Fusion and Resource Management Group are primarily concerned with tactical C2 afloat. Within the new thrust based nomenclature adopted by the CRAD organization, these activities are covered under the thrust 1.a, Integrated Naval Above Water Warfare and Shipboard Command and Control. More precisely, the activities are performed under project 1.a.5, AWW Command and Control. The overall objective of this project is to investigate system integration concepts for the automation of command and control processes dealing with information management and decision-making issues.

In that context, the mission of the DFRM group is to support the Navy in the development, acquisition, integration, and life cycle management of real-time C2 systems for target tracking and identification, situation assessment, threat assessment and resource management. This is done through R&D in the areas of sensor and information fusion, artificial intelligence, neural networks, intelligent control, system architectures, system integration, distributed and high-performance computing, and real-time software development methodologies, and their application, demonstration, evaluation and/or validation in experimental and advanced prototype CCISs.

A high-level description of the data fusion and resource management C2 processes under investigation is given below. The responsible scientists in each area are also indicated.

3.1.1 Data Fusion Definition

Throughout the 1980s the three U.S. military services pursued the development of tactical and strategic surveillance systems employing data fusion and supported extensive research in the areas of target tracking, target identification, algorithm development for correlation (association) and classification, and the application of intelligent systems to situation assessment (Ref. 6). The large amount of fusion-related work in this period raised some concern over possible duplication of effort. As a result, the Joint Directors of U.S. Department of Defense (DoD) Laboratories (JDL) convened a Data Fusion Subpanel to (1) survey the activities across all services, (2) establish a forum for the exchange of research and technology, and (3) develop models, terminology and a taxonomy of the areas of research, development and operational systems.

As a result of many years of effort to establish standardization and stability in the lexicon of data fusion, the definition of many terms is slowly achieving consensus across the diversified application community (Ref. 7). Problem-specific nuances and shading in these definitions remain but agreement on a meaningful subset of terms does seem to exist, providing an important basis for communication across specialized research groups.

Data fusion is fundamentally a process designed to manage (i.e., organize, combine and interpret) data and information, obtained from a variety of sources, that may be required at any time by operators and commanders for decision support. The sources of information may be quite diverse, including sensor observations, data regarding capability and availability of targets, topographic and environmental data, and information regarding doctrine and policy. The data and information provided by these various sources may contain numbers of targets, conflicting reports, cluttered backgrounds, degrees of error, deception, and ambiguities about events or behaviors.

In this context, Data Fusion (DF) is an adaptive information process that continuously transforms the available data and information into richer information, through continuous refinement of hypotheses or inferences about real-world events, to achieve refined (and potentially optimal) kinematic and identity estimates of individual objects, and complete and timely assessments of current and potential future situations and threats (i.e., contextual reasoning), and their significance in the context of operational settings.

The process is also characterized by continuous refinements of its estimates and assessments, and by evaluation of the need for additional data and information sources, or modification of the process itself, to achieve improved results.

3.1.2 Data Fusion Hierarchy

The process of data fusion may be viewed as a multi-level hierarchical inference process whose ultimate goal is to assess a mission situation and identify, localize and analyze threats. However, not every data fusion application is responsible for all of these outputs. Some applications are only concerned with the position and identification of objects. Other applications are primarily oriented towards the situation and how it is evolving. Still others focus on the threat and its possible impact upon achieving mission objectives. In addition, the data fusion function can be responsible for identifying what information is most needed to enhance its products and what sources are most likely to deliver this information.

Given these considerations, a complete data fusion system can typically be decomposed into four levels:

Level 1 - Multi-Sensor Data Fusion (MSDF);
Level 2 - Situation Assessment (SA);
Level 3 - Threat Assessment (TA); and,
Level 4 - Process Refinement Through Resource Management (RM).

Each succeeding level of data fusion processing deals with a higher level of abstraction. Level-1 data fusion uses mostly numerical, statistical analysis methods, while levels-2, 3 and 4 data fusion use mostly symbolic, Artificial Intelligence (AI) methods. Note that resource management in the context of level-4 fusion is mainly concerned with the information gathering process refinement (i.e., sensor management). The overall domain of resource management also encompasses the management of weapon systems and other resources. Figure 7 illustrates the overlap between the data fusion and resource management domains.

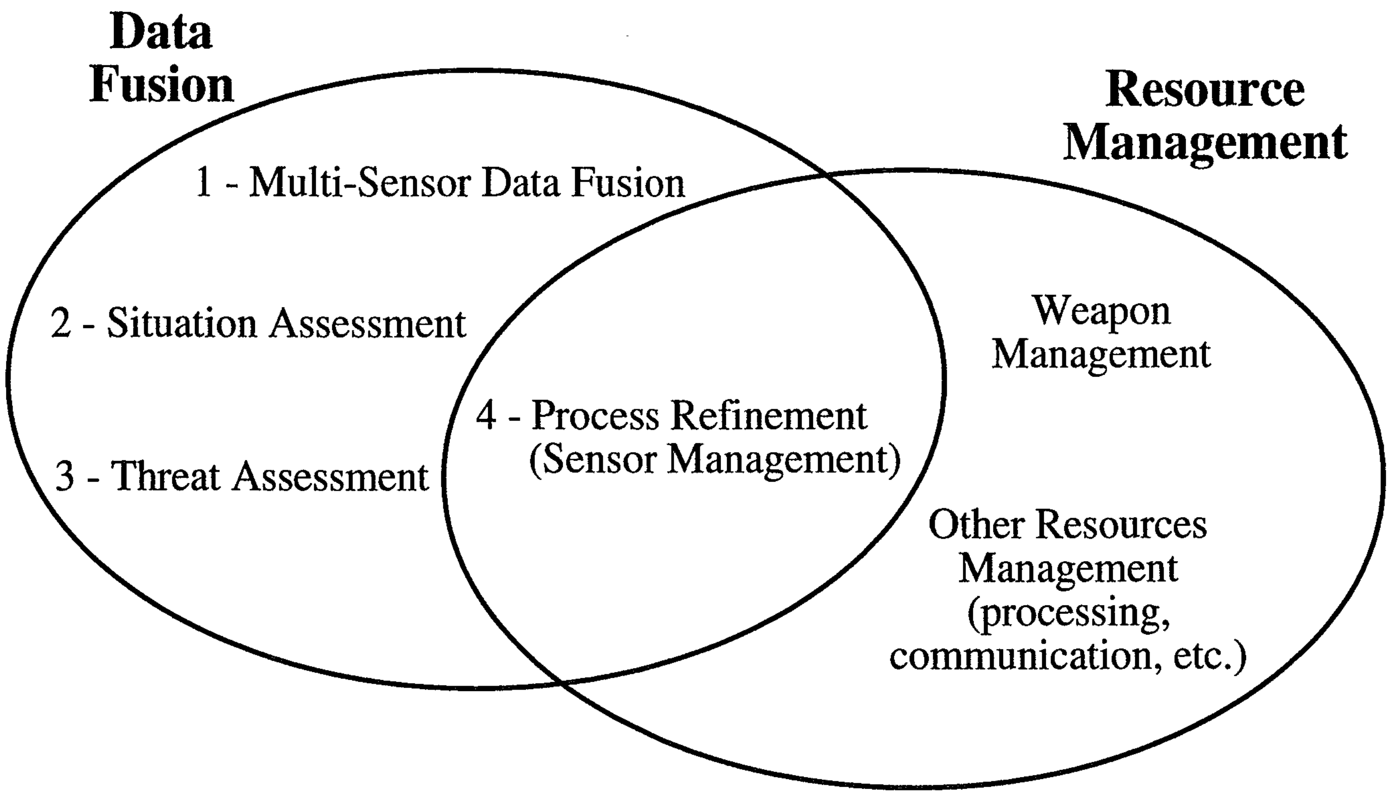

FIGURE 7 - Overlap between the data fusion and resource management domains

3.1.2.1 Level 1 - Multi-Sensor Data Fusion

(Dr. É. Bossé and Mr. J. Roy)

Multi-sensor data fusion (MSDF) is concerned solely with individual objects, first in associating the sensor outputs with specific known objects or using them to initiate new objects. Level-1 processing uses sensor data to correctly and quickly derive the best estimates of current and future positions for each hypothesized object. In addition, inferences as to the identity of the objects and key attributes of the objects are developed.

Key MSDF functions include: data alignment, data association/correlation, kinematic data fusion, target state estimation, target kinematics behavior assessment, target identity information fusion and track/cluster management.

3.1.2.2 Level 2 - Situation Assessment

(Mr. R. Carling)

Based on incomplete and inaccurate sets of data and information, situation assessment (SA) is devoted to the continuous inference of statements about the hypothesized objects provided by the lower level data fusion function in order to derive a coherent, composite tactical picture of the situation. This picture must be described in terms of groups or organizations of objects so that enemy intent can be estimated in the next higher level and decisions can be made by decision makers about how to use war fighting assets.

SA deals with monitoring and short-term or immediate situation diagnosis. Hence, SA fits hypothesized objects with known and expected organizations and events, together within the constraints of terrain and enemy tactics, to develop a description or interpretation of the current relationships among these objects and events in the context of the operational environment. The result of this processing is a determination or refinement of the battle/operational situation.

Based on the situation abstraction products and information from technical and doctrinal databases, SA also attempts to anticipate future events over a short time horizon.

Key SA functions include: object aggregation, event/activity aggregation, contextual interpretation/fusion and multi-perspective assessment.

3.1.2.3 Level 3 - Threat Assessment

(Mr. R. Carling)

Threat assessment (TA) is focused at the details necessary for decision makers to reach conclusions about how to position and commit the friendly forces. It can be viewed as a longer term diagnosis function to determine problems in the current situation and identify opportunities for taking corrective actions.

By coupling the products of situation assessment with the information provided by a variety of technical and doctrinal databases, TA develops and interprets a threat oriented perspective of the data to estimate the enemy capabilities and lethality, identify threat opportunities in terms of the ability of own force to engage the enemy effectively, estimate enemy intent (i.e., provide indications and warnings of enemy intentions), and determine levels of risk and danger.

Hence, TA uses the situation picture from level 2 and what is known about the enemy doctrine and objectives to predict the strengths and vulnerabilities for the threat forces and friendly forces. In addition, the friendly mission and specific options available to the decision makers are tested within these strengths and vulnerabilities to guide decision making.

Key TA functions include: enemy forces capability estimation, predict enemy intent, identify threat opportunities, multi-perspective assessment and offensive/defensive analysis.

3.1.2.4 Level 4 - Process Refinement (Resource Management)

(Dr. É. Bossé, Dr. B. Chalmers and Mr. J. Roy)

Information resource management, level 4 processing, closes the loop by first examining and prioritizing what is unknown in the context of the situation and threat and then developing options for collecting this information by cueing the appropriate sensors and collection sources.

3.1.3 Resource Management Definition

(Dr. B. Chalmers)

Situation and threat assessment, together with command team interaction, as required or as response time permits, is used to drive the planning and decision support functions for allocating and scheduling the use of critical defence resources and coordinating defence actions in support of the mission. Determination of the various options for use of the resources and the selection of the best course of action in a given situation is known as Resource Allocation. Resource Management refers to the continuous process of planning, coordinating and directing the use of the ship or force resources to counter the threat. It is concerned with issues of both command and control.

3.2 Multi-Sensor Data Fusion

The overall aim of the MSDF activity at DREV (Refs. 1, 8-14) is to analyze, develop and evaluate advanced techniques to automatically produce the optimal estimate of the position, kinematic behavior, and identification of all objects surrounding a single ship, mainly through the fusion of data from dissimilar organic sensors (e.g., radar, E-O, ESM), while including inorganic information (e.g., data coming over communication links, intelligence reports, etc.). The use of the latter type of information is directed towards the potential enhancement of the performance of the different sensor data fusion sub-processes. The specific aim of the MSDF project is to demonstrate cooperative, synergistic, and efficient utilization of all of the CPF AWW sensor elements.

Figure 8 emphasizes the typical inputs to the MSDF process. Contacts (or raw measurements) and tracks from multiple dissimilar sensors are processed to form the tactical picture in the local area surrounding a single ship platform. This sensor data information can be generated locally, or it may come from other platforms via communication data links. Typically, modern sensors process their own raw data to produce local tracks. However, depending on the selected fusion architecture, it is assumed that one also has access to the raw sensor reports.

Figure 9 is a decomposition of the MSDF process into its constituent sub-processes. Those that are typically identified in the literature as necessary to perform the level-1 MSDF function are data alignment, data association or correlation, kinematic data

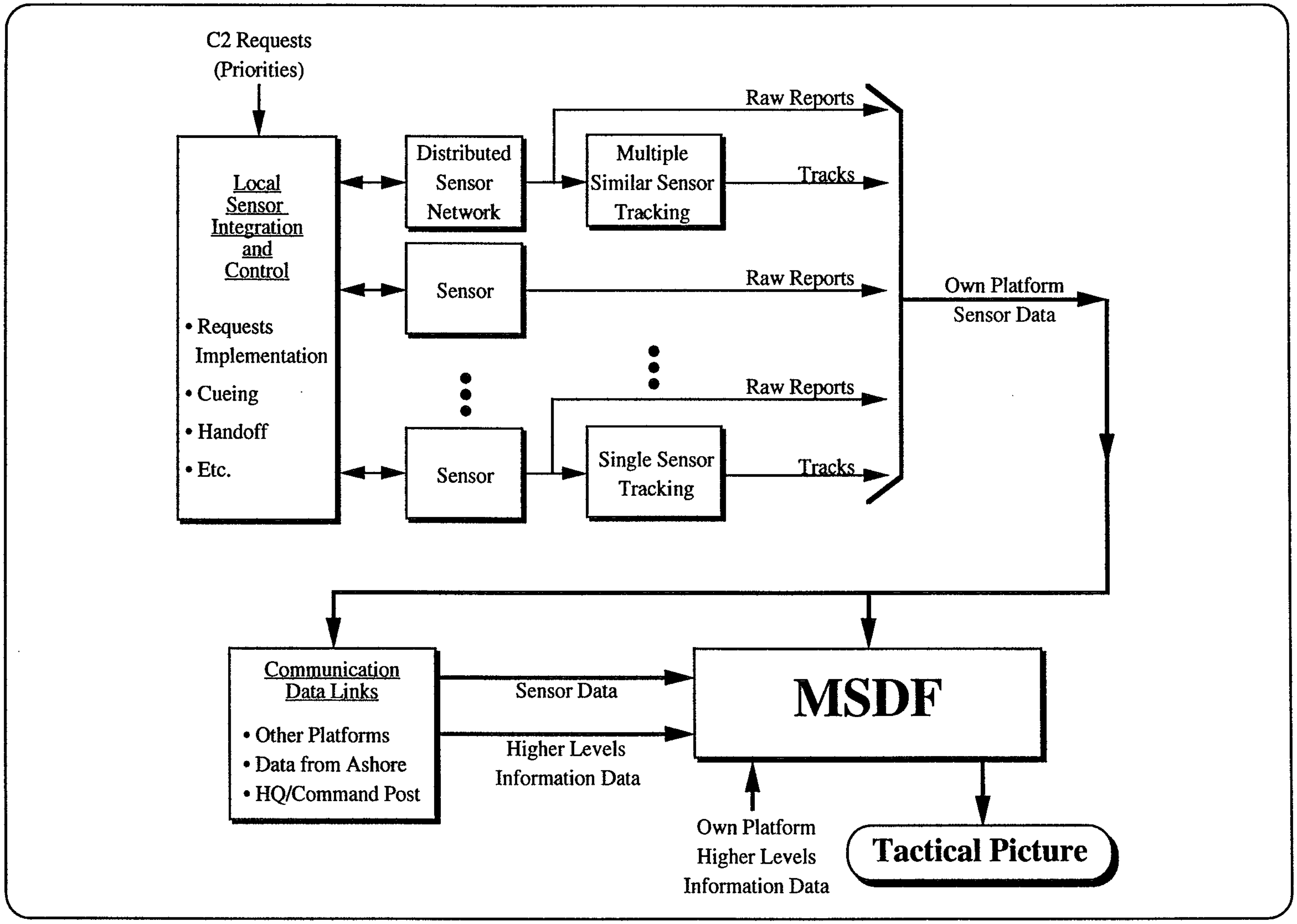

FIGURE 8 - Typical data inputs to an MSDF function

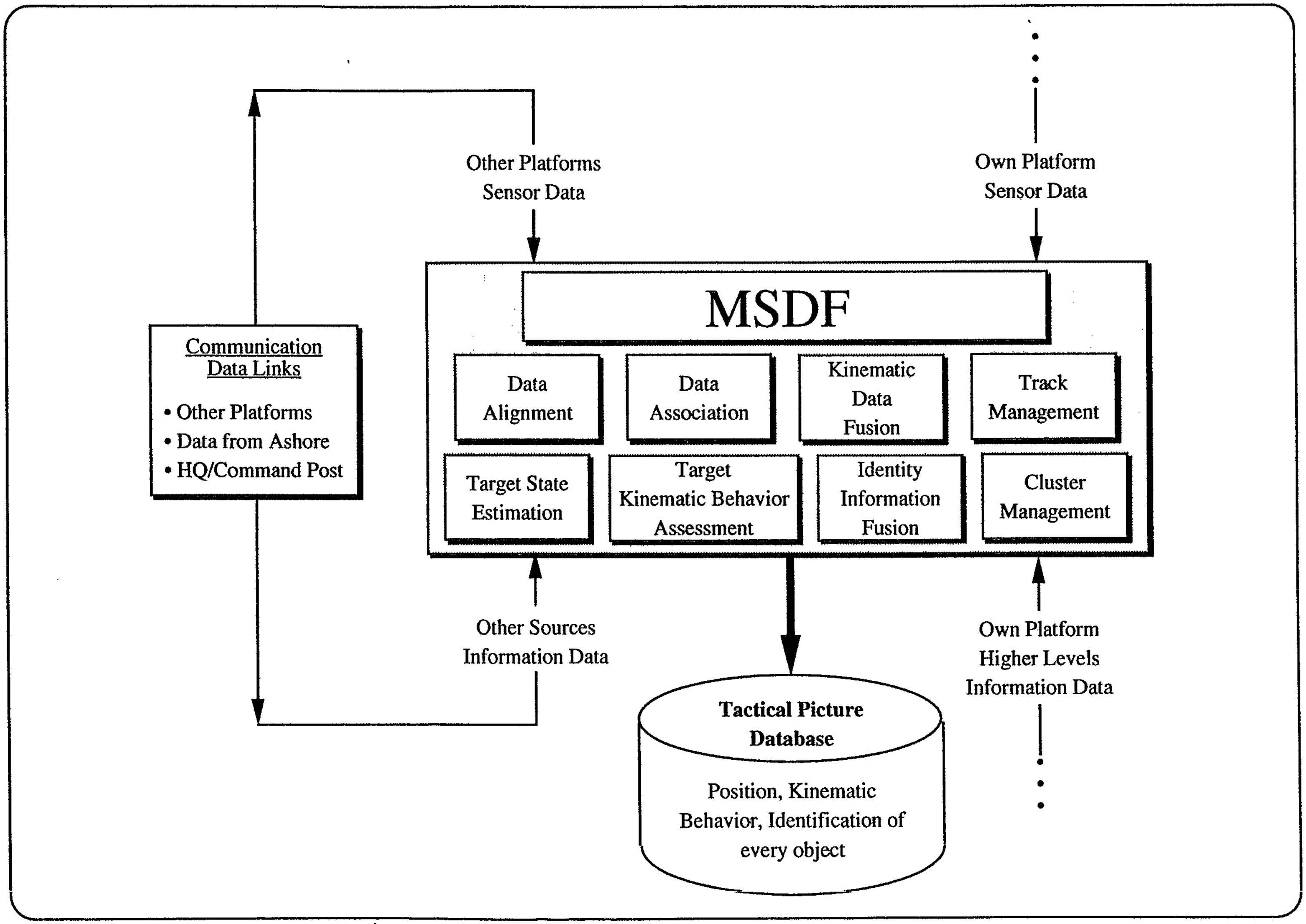

FIGURE 9 - Functional decomposition of the MSDF process

fusion, target state estimation, target kinematics behavior assessment, target identity information fusion and track management. Each sub-process identified in Fig. 9 is being analyzed and studied under the project in terms of the specific algorithms and techniques applicable to each process. Figure 10 is an overview of the principal issues that have been investigated so far with respect to the MSDF sub-processes illustrated in Fig. 9.

The partitioning of the sub-processes is sometimes arbitrary and depends on a specific architecture for physical implementation. Therefore, the flow of information from one process to the other is also being studied under the project so that various configurations or types of architecture, that make use of basic algorithms for each sub-process, are investigated as options to implement the overall MSDF function.

3.2.1 MSDF Results

Up to now, a large portion of the research conducted by the Data Fusion and Resource Management Group in the MSDF domain has been done through collaboration with universities and Canadian industry. Results have been documented in several reports (Refs. 15-42). The C2 Division has also been strongly involved as scientific advisor for two DIRP projects undertaken by the Canadian industry and related to sensor data fusion. Again, results have been documented in several reports and papers (Refs. 43-49). The following paragraphs give, with respect to each of the major MSDF sub-processes, a very brief overview of the research issues that were addressed. Details, and discussions of other aspects not covered here, can be found in the references.

The term "MSDF architecture" is used to indicate, based on the level at which the sensor data are fused (i.e., signal, contact or track level), the general method (or philosophy) used to combine the sensor data into global tracks within an MSDF function. Figure 11 illustrates on a single diagram the usual definition of three types of MSDF architecture for two generic sensors. The MSDF architecture is an important issue since the fusion benefits are different depending on the way the sensor data are combined. Various theoretical analyses on different types of multiple sensor data association and fusion architecture have been performed under the MSDF project at DREV (Refs. 18-19, 27, 31, 33, 38). Comparative studies (i.e., advantages vs. disadvantages, trade-offs) have been conducted for the sensor-level method vs. the central-level approach in terms of computational, data base, and communication requirements. The possibility of using a

Data Alignment (Registration)

- Effects of Misalignment
- Time Alignment
- Spatial Alignment
- Estimation Techniques (Solutions)

Target State Estimation

- Kalman Filtering
- Adaptive Kalman Filtering
- Extended Kalman Filtering
- Multi-sensor Filtering
- Computational Load
- Coordinate Systems

Data Association

- Correlation Methods and Techniques (Gating, NN, PDA & JPDA, MHT, etc.)
- SS/MTT to MDS/MTT Extension
- Dissimilarity Among Measurements
- Combined Attribute / Positional
- Track Management (Initiation, etc.)

Target Kinematic Behavior Assessment

- Target Dynamic Models
- Two / Three State Models
- White / Colored Noises
- Target Maneuver Detection

Kinematic Data Fusion

- Contact vs. Track Fusion
- Contact / Track Complementarity
- Central (Global) Track Maintenance
- Tracking with Combined Active and Passive

Identity Information Fusion

- Bayesian, Dempster-Shafer and Fuzzy-Logic
- Attribute Data Base Requirements
- Attribute Fusion
- Identity Declaration Fusion
- Track-to-Attribute Measurement Correlation

FIGURE 10 - Overview of some issues investigated under the MSDF project at DREV

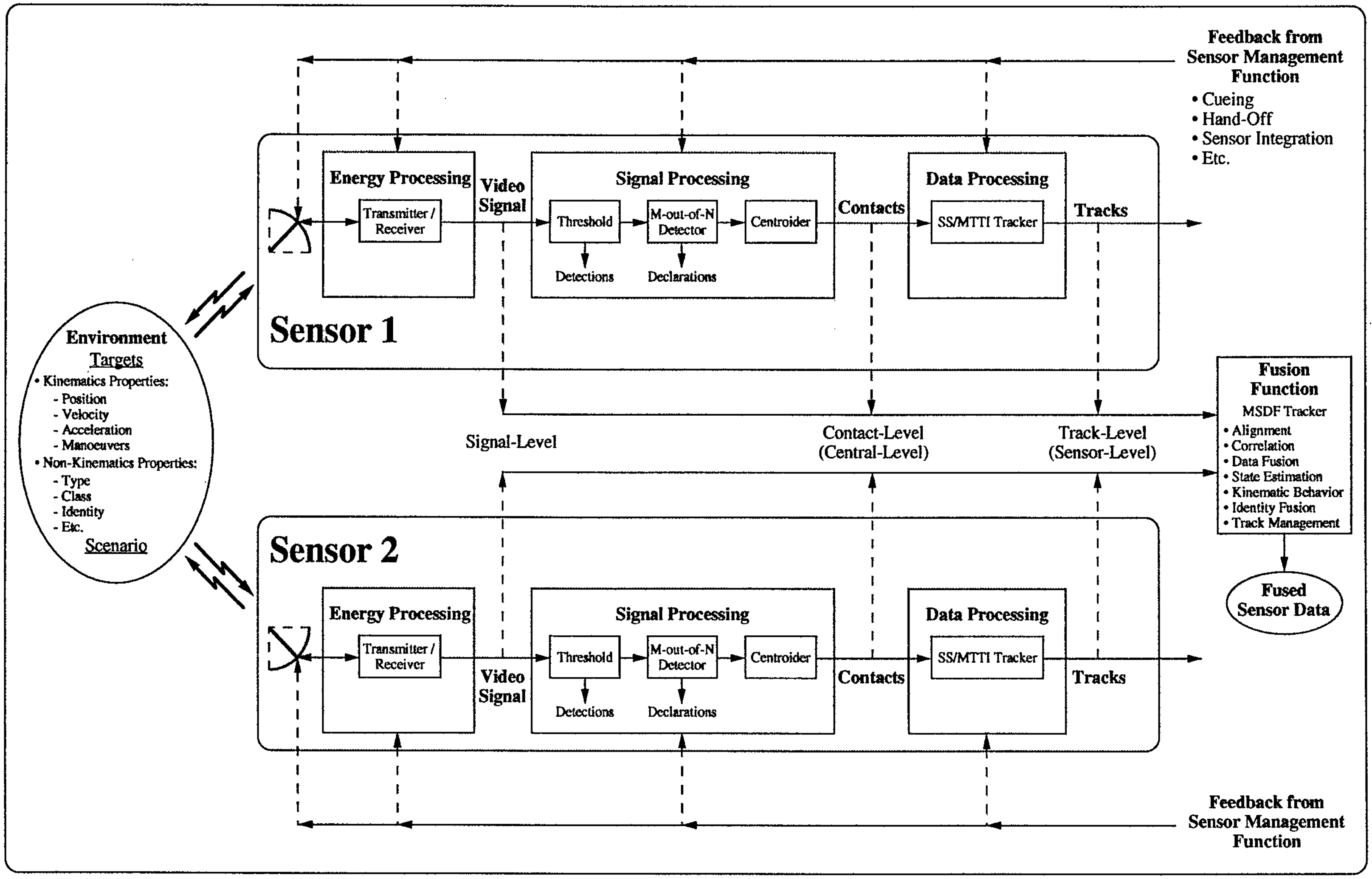

FIGURE 11 - Definition of three types of MSDF architecture for two generic sensors

mixture of these two types of architecture to form a hybrid (or combined) tracking structure has also been investigated.

The effects of misalignment on the performance of the data association and fusion techniques have been studied under the MSDF project at DREV. Both spatial and time alignment problems have been addressed. Solutions to misalignment have been investigated, based on filtering theory (Refs. 18, 27, 31).

Target state estimation is a statistical process used to infer, in some optimal fashion, the state of a dynamic target based on collected noisy sensor measurements. The purpose of the kinematic behavior assessment MSDF sub-process is to support and complement the target state estimation sub-process during target maneuvers. Both processes together are generally referred to more simply as the target tracking process per se. Multiple issues involved in addressing the problem of high precision tracking of a target have been studied in depth. Indeed, the overall Kalman filtering domain as applied to target tracking has been surveyed in order to sum up the state-of-the-art in target state estimation based on classical estimation theory. Among the issues studied, basic Kalman filters (i.e., covariance vs. information type filters, coupled vs. decoupled filters, extended Kalman filter, etc.), adaptive Kalman filtering structures for maneuvering targets (e.g., the Interacting Multiple-Model (IMM) algorithm, etc.), target state models (e.g., two-state filters, three-state filters, etc.), assumed target process noise (e.g., white noise acceleration, colored noise, etc.), target maneuver detectors (e.g., fading sum or sliding sum, etc.), filter initialization concepts, the effect of measurement dropout (i.e., non-unity probability of detection), and the selection of the filter parameter values for performance optimization based on physical considerations have been addressed (Refs. 18, 30, 32-42).

The fundamental problem in a multi-sensor multi-target scenario lies in resolving the ambiguous measurement association decisions. It is difficult, when tracking multiple targets in a cluttered environment, to select among many returns the correct or true return from a given target to be used within the tracking algorithm for track updating. Various data association approaches proposed in the MSDF literature (e.g., ellipsoidal gating, Nearest-Neighbor (NN), Multiple Hypothesis Tracking (MHT), Joint Probabilistic Data Association Filter (JPDAF), etc.) have been reviewed and described in depth under the MSDF project at DREV (Refs. 18-19, 26-29, 31). The extension of these basic algorithms and techniques has also been studied in order to use them within a multiple sensor configuration. Many other aspects of the sensor data correlation process have also been investigated. In particular, how to deal with the measurement vector (or state vector if one considers tracks) dissimilarities between two or more sensors (e.g., different dimension, dissimilar type of information, etc.) has been considered. This issue arises, for example, when one tries to associate active radar data (including range information) with passive IR sensor data (no range information). The resolution differences between sensors (e.g., the IR sensor resolves multiple targets when a radar makes a single target declaration), the potential problem when multiple ESM tracks (multiple emitters) are established from a single target that is also seen by another sensor, the association of IR and radar data with ESM data when the latter sensor has only a relatively inaccurate angle in common with the two others, are other issues that have been addressed.

Vastly differing methodologies have been successfully applied to the generic sensor fusion problem. A review of proposed theoretical fusion techniques in the MSDF literature, and the practical implications of each, has been conducted (Refs. 11, 15-16, 18-19, 24-25, 27, 31, 33, 38). The majority of generally applicable techniques appeal to probability theory to achieve descriptions of the sensor's abilities (qualitative models) with appropriate statistically based fusion schemes. These probabilistic approaches can be further separated into techniques utilizing statistical decision theory, maximum likelihood techniques, while the majority incorporate linear Bayesian estimation techniques.

The target identification aspect has also been considered in order to produce the complete tactical picture required by the subsequent C2 processes. Two approaches have been studied in parallel to investigate and evaluate fusion techniques capable of combining uncertain information in the form of identity information. The first approach deals with attribute information (Refs. 15-16) while the second one focuses on identity declarations (Ref. 11).

In the first study, attribute information obtained from various sensors is compared to a Platform Data Base containing all the possible identity values that the potential target may take. Each record of this data base contains information related to the measured sensor attributes. Therefore each sensor's attribute information is translated into a subset of the Platform Data Base and a confidence level for each subset is then computed. The subsets, called propositions, are then combined using Dempster-Shafer Evidential theory. However, as various propositions are combined over time, the Dempster-Shafer combination rules have a tendency to generate more and more propositions which in turn must be combined with new propositions. This problem is known to increase exponentially. The algorithm proposed rigorously controls the amount of input and output propositions by pruning the "unessential" propositions and selecting the "best" identity propositions by applying selection criteria. Therefore a finite number of candidate identifications is retained. This technique is called the truncated version of the Dempster-Shafer Evidential approach and has been applied to fuse attributes from the sensor suite of a frigate size AWW ship. The sensor suite considered consists of long and medium range radars, IRST, IFF and ESM sensors.

In the second study, the emphasis is given to the idea that sensors are self-contained and capable of estimating identity declarations. Such a declaration specifies the detected object; it can consist of a general classification of which the observed object is a member (surface combatant), a specific type of ship (frigate), a specific class (City Class) or a unique identity (Ville de Québec). Identity declaration can also include information concerning the threat designation of an object: pending, unknown, assumed friend, suspect, friend, neutral or hostile. The study also assumes that identity declarations are probabilistic in nature such that each declaration is characterized by a confidence value and that the declarations are independent.

The MSDF environment poses unique challenges to the mandate of the track manager and thus motivates the development of advanced management schemes. In particular, the MSDF function must exploit the complementary characteristics among the multiple sensor reports in order to perform track initiation and maintenance better. Track management concepts have been investigated under the MSDF project at DREV. Results have been documented in several reports (Refs. 18-19, 26-29).

3.2.2 The CASE_ATTI Tool

The CASE_ATTI (Concept Analysis and Simulation Environment for Automatic Target Tracking and Identification) system is a highly modular, structured and flexible simulation environment providing the algorithm-level test and replacement capability required to study and compare the technical feasibility, applicability and performance of advanced, state-of-the-art MSDF techniques (Ref. 1).

Figure 12 illustrates the global structure of the CASE_ATTI system. The sensor module is responsible for providing realistic measurement data to the tracking algorithms. Given a user-defined scenario, it generates true target positions and measured target positions, which are subsequently made available to the tracking module. Currently, the module supports radar and IRST sensor simulations. More specifically, the CPF radars currently supported by the CASE_ATTI sensor module are the SG-150 Sea Giraffe and the AN/SPS-49 long range radar. An adaptation of the CASE_ATTI radar model is ongoing to also support the CPF fire control system STIR radar. A contract is about to begin for the integration of ESM data into the sensor module. This ESM simulation capability will be representative of CANEWS.

The current tracking module in CASE_ATTI supports a wide variety of tracker architecture types, varying from a simple single sensor tracker to an arbitrarily complex hierarchical multiple sensor topology. Its design has the capability of simulating a sensor-level, central-level or hybrid tracking architecture as required. Finally, the data extraction, visualization and analysis module comprise a set of computer tools implemented in CASE_ATTI to help the MSDF designer in his assessment of the performance of the algorithms and techniques.

It is believed that large portions of CASE_ATTI could become an integral part of the ASCACT testbed. The sensor module (i.e., the sensor simulations, the target container, etc.) could be modified to act as a stimulator for the ASCACT testbed. This would necessitate that feedback information be incorporated and used in the sensor module in order to close the loop with MSDF, STA and RM, and accommodate the simulation of highly dynamic and interactive scenarios. The tracking module could be used to create any MSDF architecture. The performance evaluation process could be used to evaluate the ability of the MSDF system to generate measured and estimated tactical pictures that accurately reproduce the ground truth tactical picture.

However, before any of these possibilities is further developed, it is necessary to consider real-time aspects as required for ASCACT. In that respect, most of the sensor module could probably be used as it is. However, the tracking module encompasses a lot of overhead code, the purpose of which is to provide the required flexibility to explore different MSDF architectures. For the ASCACT testbed, it is recommended that a specific MSDF architecture be first selected, and then the appropriate MSDF code be extracted from

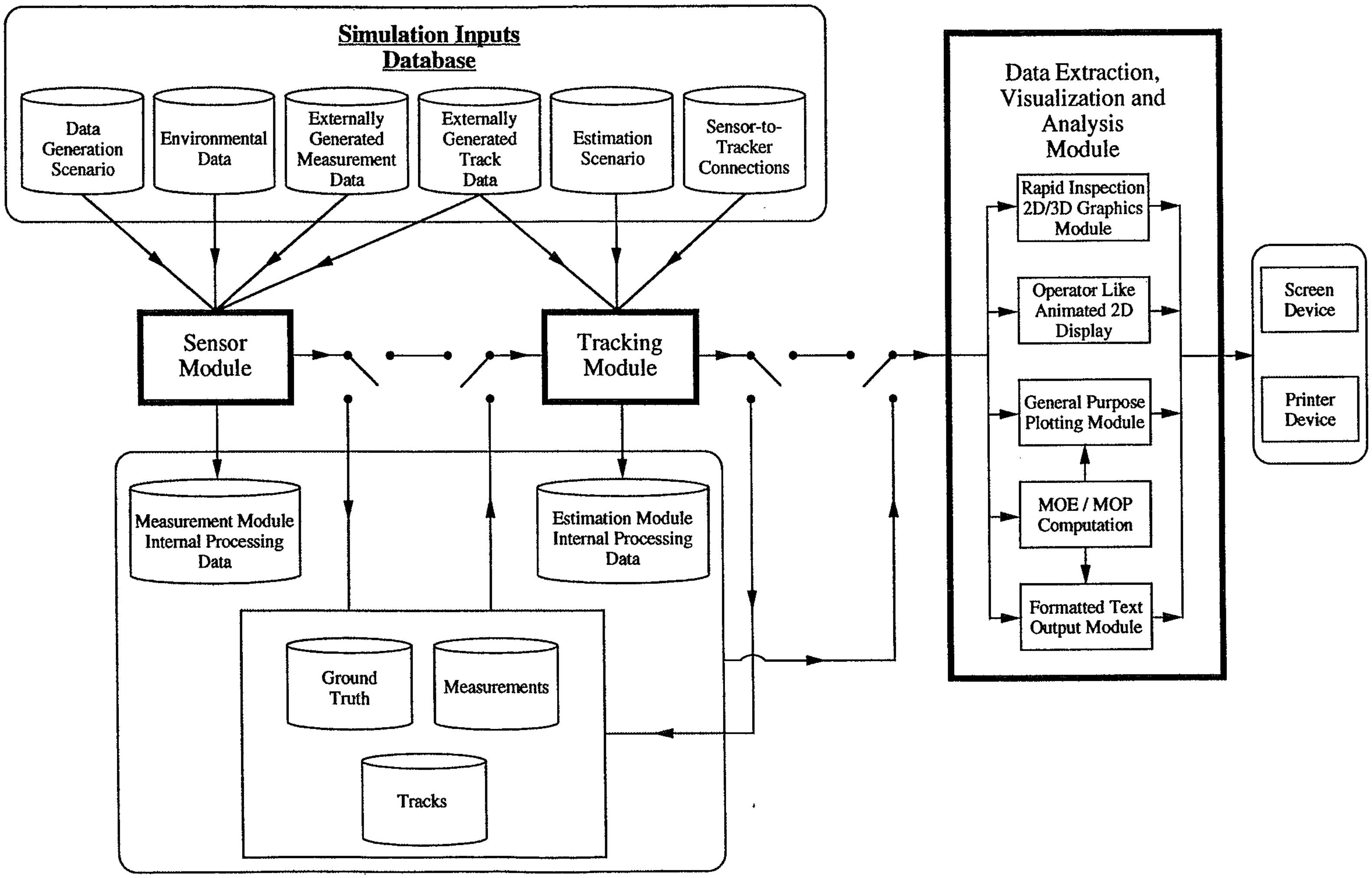

FIGURE 12 - Global structure of the CASE_ATTI system

CASE_ATTI to be reused in the testbed. Further analysis is however required to confirm the feasibility of this approach.

3.2.3 Ongoing R&D Work Performed Under Tasking by DMSS 6

Most of the current research in MSDF is dedicated to the development and application of new techniques, but little has been performed to determine how well such methods apply to a practical system. The CPF is a very interesting platform for MSDF application. Reference 1 discusses an ongoing study making use of the CASE_ATTI system to support the development of MSDF concepts that could apply to the current CPF sensor suite, as well as its anticipated upgrades (i.e., MFR, IRST, CANEWS 2), in order to improve its AWW performance against the predicted future threat. The study is sponsored by DMSS 6 through a task entitled: "Development of Sensor Integration Techniques for CPF AWW Sensor Suite Configurations". It aims to identify and develop techniques for combining Radars/EO/ESM data, and to evaluate the real benefits of the combination. Two major aspects need to be addressed for this application: first, the representation of the actual CPF sensor suite to establish its baseline performance, and second, the quantification of the performance improvements gained when using an upgraded sensor suite combined with advanced MSDF concepts.

The definition of the CPF baseline performance for this study comprises two related aspects. Firstly, the performance of the current sensors operating in a stand alone mode is evaluated. Secondly, the global performance of the complete sensor suite is evaluated taking into account the limited integration that is performed within the current CPF Command and Control System (CCS). In both cases, it is assumed that the sensors are performing in accordance with their specifications. It is out of the scope of this project to verify if the sensors meet their specifications.

The current AWW sensor suite of the CPF comprises the SPS-49 long range 2-D radar, the Sea Giraffe medium range 2-D radar, the CANEWS ESM and the Separate Track and Illumination Radar (STIR). The surveillance radar models used in this study allow the generation of measurements, as well as a representation of the tracking performed inside the sensors. As a result, the simulated data are very close to the outputs of the SPS-49 and Sea Giraffe. This represents an original novelty of our simulation environment.

The baseline performance will be evaluated against the predicted future threat. More precisely, all performance evaluations will be against the AWW mission and threat requirements, including maneuvering targets and if possible ECM conditions, which are currently being specified by the Canadian Navy. The environmental scenarios to be used will be those developed by DREV for the NATO Anti Air Warfare System (NAAWS) program.

The Canadian Navy is planning to upgrade the CPF sensor suite. However, the development and/or acquisition of advanced AWW sensors, although necessary, may not be sufficient for providing the required protection for ships against the anticipated future threats. The simple interfacing of these components is not enough because such independent AWW elements are seldom used in a coordinated manner, which typically leads to a confusing and time-late decision environment for the ship's commander. Hence, the effectiveness of the AWW system is not completely determined by the capabilities of the AWW sensor suite alone, but also by the effectiveness of the system integration which must focus on cooperative, synergistic, and efficient utilization of all of the AWW sensors.

In that context, an incremental approach has been chosen to demonstrate how the performance of the CPF sensor suite can be improved using an upgraded sensor suite combined with advanced MSDF concepts. The idea is to compare alternative methods against a common problem and to evaluate the results with respect to the baseline performance. The first step is to allow minor modifications to the existing system such that the current tracking algorithms for each sensor taken individually can be improved with advanced techniques, and sensor data fusion can be used within the CCS. This is accomplished within the CASE_ATTI system. CASE_ATTI allows the possibility of trying all kinds of tracking algorithms as well as assessing the performance of various types of fusion architecture. Any resulting performance improvements with respect to the baseline performance will be quantified.

The second step is to add an Infrared Search and Track (IRST) simulation to the current representation of the CPF sensor suite. The required MSDF techniques and algorithms to support this addition to the sensor suite will be identified and developed. The performance obtained through MSDF for the modified sensor suite will be evaluated and any resulting improvements will be quantified.

The last step is to further modify the current CPF sensor suite by replacing the STIR and the Sea Giraffe simulations with a Multi-Function Radar (MFR) model, and by upgrading the CANEWS ESM simulation. The MSDF algorithms and techniques required for the integration of this upgraded sensor suite will be identified and developed. Again, any resulting performance improvements will be quantified.

3.2.4 Porting of the MSDF Results in ASCACT

As presented in section 3.2 above, a lot of work on the use of the MSDF technology in a naval context has been conducted by DREV. These research activities have resulted in a major improvement of the knowledge base at DREV in the field of MSDF. As a result of this work, DREV has acquired the capacity to advise the Forces in the selection of integrated surveillance and tracking systems suitable to fulfill their requirements, and, in the optimization of the operation of these systems to obtain the best performance. What remains to be done for the ASCACT project is to provide an explicit definition of the MSDF process required for the CPF (or at least a specification of the configuration that will first be used in the initial MSDF/STA/RM baseline application implementation in the ASCACT testbed) by selecting and combining appropriate candidate techniques or issues previously studied by DREV. This selection of MSDF algorithms among those investigated at DREV must also consider their implementation in real-time to be suitable for the ASCACT testbed. It is believed that the level of effort to achieve this goal is not very high and that a recommendation (including a detailed specification) can be developed in the framework and timeline of the ASCACT Integration Working Group activities.

3.3 Situation and Threat Assessment

The purpose of this section is to summarize all the important research activities in Threat Evaluation and Weapon Assignment (TEWA) and Naval Situation Assessment that have taken place at DREV over the past five years and indicate their potential connection with the ASCACT project. There were five major research activities in this area:

(1) the building of a knowledge-based Threat Evaluation and Weapon Assignment process for a single stationary AAW destroyer attacked by anti-ship missiles.

(2) the building of a multiple ship AAW Simulator for studying the decision making of the knowledge-based Threat Evaluation and Weapon Assignment process described in (1) for each ship that is attacked by anti-ship missiles.

(3) the building of a TEWA resource loading study for studying the messages sent between a TRUMPlike ship's sensors and weapons and the Battle Management Functions residing on its command and control computers.

(4) the design of real-time knowledge-based systems and fuzzy expert systems for naval Situation and Threat Assessment (STA) where multiple air platforms (aircraft, anti-ship missiles) are attacking warships, or aircraft and helicopters are conducting various operations (not necessarily hostile) in the warships' airspace.

(5) the implementation of a real-time knowledge-based system for naval STA using the MUSE shell executing on a single processor workstation.

Section 3.3 describes the work done in each of these projects.

3.3.1 Knowledge-Based TEWA

A detailed description of the knowledge-based TEWA and the sensor and weapon models interacting with it can be found in Refs. 50-54.

A knowledge-based threat evaluation and weapon assignment (TEWA) process has been built in SMALLTALK 80/HUMBLE by Thomson CSF Systems Canada. The knowledge-based system consists of four knowledge bases comprising 110 rules altogether. This knowledge-based system was initially developed for a single stationary AAW destroyer attacked by radar guided anti-ship missiles. The knowledge-based system consisted of two parts: a TEWA target track generator and the TEWA simulator containing the actual knowledge-based system. Both of these two parts were coded in SMALLTALK 80, while the knowledge-based system was built from the HUMBLE shell. In the TEWA simulator, there are basic models for the surveillance radars, fire-control radars, electronic support measures (ESM) and infrared search and detect devices. In addition, there is a sensor data fusion process that is modeled using sensor level fusion. This means that tracks are formed for the air threats at each sensor node after going through the operations of data association and track correlation. Finally, tracks from various sensors are fused together using minimum variance fusion. Various kinds of air threats : high diver, shallow diver, sea skimmer and hybrid diver are completely simulated from their launch point until they reach their impact point with the ship. The knowledge-based system performs a threat evaluation for each track coming from the sensor data fusion process and this is followed by the execution of a resource allocation plan assigning as many weapons as possible to all the ranked tracks. The sensor fusion and resource allocation parts of the KBS TEWA were developed five years ago when integrated work between scientists studying MSDF, STA and RM was less of a concern.

The design of the knowledge-based system for the single, stationary AAW destroyer is given in Fig. 13. It consists of knowledge bases, and a ranking of reactions function. The knowledge bases are called respectively: Target Evaluation, Result Evaluation, Force Resources Evaluation and Candidate Reaction Evaluation. The Target Evaluation knowledge base consists of rules for threat identity, threat radar mode, threat engagement status and threat kinematic parameters. The other rules are rules for combining the threat identity characteristics, the threat kinematic values, the radar mode characteristics and the engagement status characteristics. They combine the above four characteristics to produce a value of threat level. There is a Result Evaluation knowledge base that does kill assessment for each kind of hardkill and softkill weapon system on the ship. There is also a Force Resources Evaluation knowledge base which monitors the availability and stock level of weapons systems before assignment. There is a fourth knowledge base which assesses whether candidate hardkill or softkill weapons can be assigned to threats.

Results from the knowledge-based TEWA are shown in Refs. 55-57. An alternative approach using a conventional TEWA is described in Ref. 58, while additional work to close the TEWA loop for the chaff reaction is described in Ref. 59.

3.3.2 The Anti-Air Warfare Simulator

The twenty modeled entities of the AAW Simulator were designed according to the specifications of Refs. 2-4, coded in SMALLTALK 80 and subjected to acceptance tests.

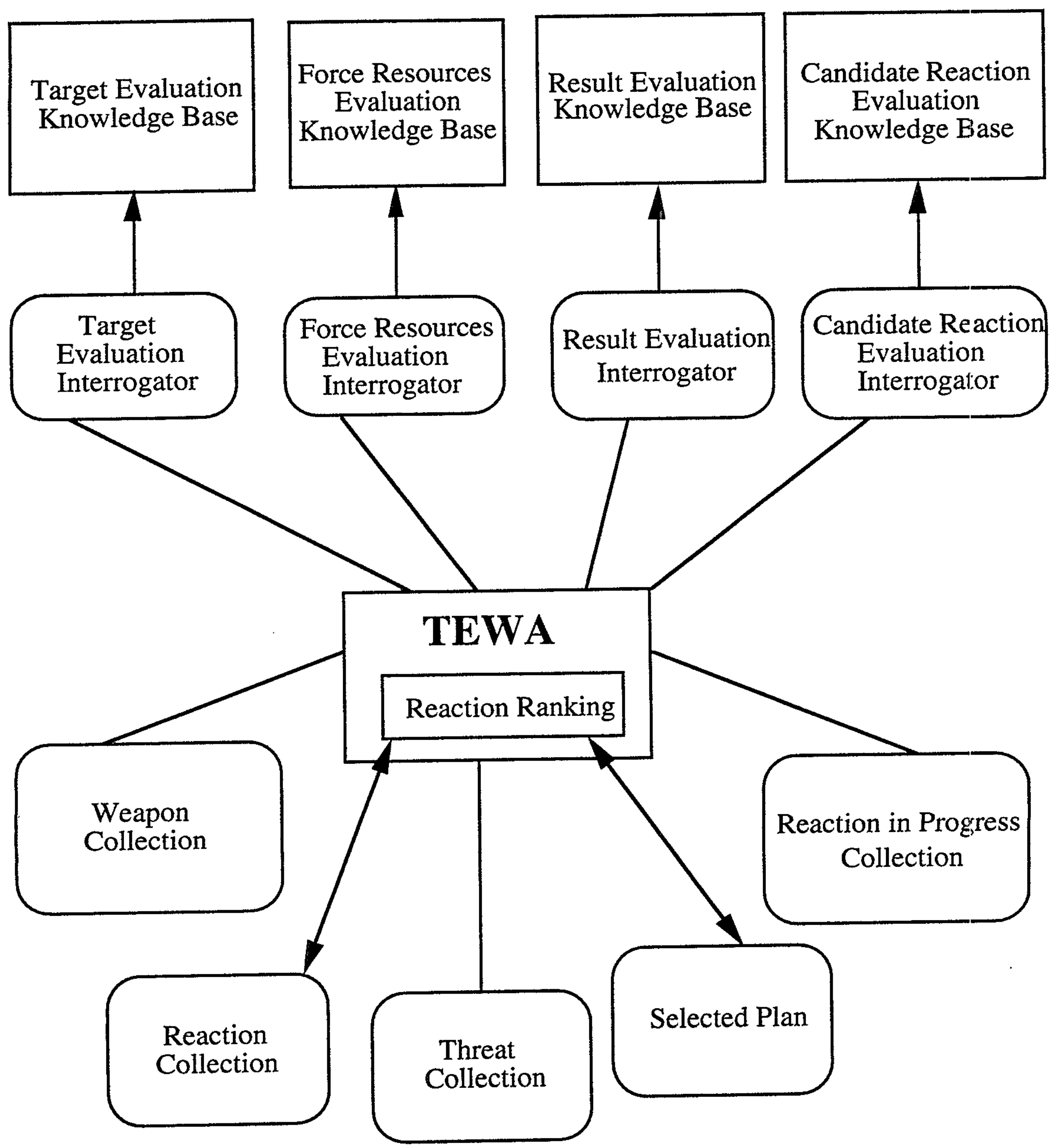

FIGURE 13 - An architecture for the knowledge-based system

Since the results obtained from the first coding of the AAW simulator were not entirely correct, the functionality of the modeled entities was recently revised by Thomson CSF Systems Canada and the entities have been coded again. The following is a list of modeled entities of the AAW Simulator which does not include the TEWA modeled entity.

- Surveillance Radar Model
- Fire-Control Radar Model
- Electronic Support Measures System
- Infrared Search and Track System
- Surface-to-Air Missile Model
- Threat Model
- Chaff and Chaff Controller Models
- Naval Gun and CIWS models
- Tracking Processor
- Continuous Wave Illuminator
- Sensor Data Fusion Processor(SDFP)
- Fire-Control Processor
- Missile Launch Controller (MLC)
- Jammer
- Sensor Management Processor
- Internal Communication System
- External Communication System
- Force Resource Data Fusion Processor
- Seaborne Platform

The knowledge-based TEWA system discussed in section 3.3.1 that was developed for a single stationary AAW destroyer has been modified in order to accommodate hardkill or softkill reactions deployed from a maneuverable ship. The AAW Simulator is being developed for several warships which can maneuver when attacked by anti-ship missiles. Ship rotation is used to support hardkill reactions. More specifically, ship rotation may occur in order to unmask a fire-control radar or naval gun that is in a blind zone. Ship rotation is also employed to use the chaff system more effectively against anti-ship missile threats. Although the generic sensor and weapon models of the AAW Simulator are accurate, no use is made at the moment of doctrine to specify the interference caused by the use of operational hardkill and softkill systems. Currently, the knowledge-based TEWA of the AAW simulator will allocate a rotation before deployment of hardkill and/or softkill weapons. These rotations may interfere with each other in the sense that a hardkill rotation is in the starboard direction while a softkill rotation is in the port direction. The AAW simulator indicates each occurrence of hardkill/softkill interference and the effect of this interference on the number of anti-ship missiles destroyed or decoyed. The only other kind of interference considered so far is spatial interference caused by a chaff cloud obscuring a fire-control radar line of sight.

The AAW Simulator simulates the launching of anti-ship missiles from aircraft at long range (200 km) or medium range (70 km). The types of anti-ship missile simulated are high divers, shallow divers or sea-skimmers. Threats have radar, infrared or anti-radiation missile seeker heads. The AAW Simulator simulates the acquisition and tracking(lock-on) modes of the radar anti-ship missiles. During acquisition mode, the radar seeker head calculates a signal-to-noise ratio for each target within its field of view (a ship of the convoy, chaff cloud). The seeker head chooses the target with the highest signal-to-noise ratio and remains locked onto it until shot down by a surface-to-air missile or the seeker head loses the missile radar signal because the signal-to-noise ratio suddenly becomes small. The infrared seeker head modeled is the non imaging type of IR seeker head (reticule seeker head). The anti-radiation seeker head model is similar to the radar seeker head model.

In the single ship scenarios of the AAW Simulator, a CPFlike ship detects the anti-ship missiles at long range and the tracking processor generates radar tracks of the threats. As soon as the tracks are within range of the ship's fire-control radar, tracking of selected targets begins as dictated by the threat evaluation function. Since the tracks are extremely fast and take no evasive action when tracked by a fire-control radar, it is concluded that they are not civilian or friendly aircraft. The knowledge-based TEWA then decides whether rotation can take place before the threats reach the ship. If so, rotation takes place so that the ship can be in a position where it can use all hardkill weapons against the threats. The output from the AAW Simulator is a series of assignments of hardkill and softkill weapon systems against the threats attacking the ship which are designated by the threat evaluation function. If chaff is deployed, the ship may have to make a further small rotation to use chaff more effectively.

In the multiple ship scenarios, a TRUMPlike ship is the anti-air warfare commander (AAWC) of a group of four ships including two CPFlike ships. Anti-ship missile threats with the same kind of seeker heads as in the single ship case are targeted from medium range at each of the four ships. The ships reason about these radar air tracks as before and take up the best position for use of hardkill weapons against the threats. The output from the AAW Simulator is a series of assignments of hardkill and softkill weapon systems for each ship of the convoy against the threats designated by the ship's threat evaluation function. The AAW Simulator is used to study issues affecting the design of a knowledge-based TEWA in a convoy of ships, e.g., the number of cases where surface-to-air missiles fired from two different ships are aimed at the same threat (overkill), chaff deployed from one ship to decoy threats causes the threats to hit another ship (fratricide), rotations from two different ships to use their hardkill/softkill weapons in a more successful way results in a collision course for each ship, and the number of cases where the rotation sense for deployment of hardkill and softkill weapons is opposite (interference).

Some of the modeling done to integrate the extended knowledge-based system into the AAW Simulator is described in Refs. 60-62.

3.3.3 TEWA Resource Loading Study

A TEWA resource loading study has been carried out by Thomson CSF Systems Canada to simulate the loads placed on the command and control processors of a TRUMP like ship by battle management functions assigned to the ship's UYK 505 processors. The battle management functions were derived from a generic TEWA study preceding the work described in section 3.3.1 which described a general air defence process, listed its functions and subfunctions and presented flow diagrams specifying the data flow between functions and subfunctions of the air defence process. In this study, estimates are made of the cycle time taken by each UYK 505 processor for executing lines of pseudocode representing the battle management functions. The simulation also measures the queue sizes of messages sent from the ship's sensors and weapons through the SHINPADS bus into the command and control computers. The data flow through the SHINPADS bus of each warship and through the LINK 11 system connecting several ships are also outputs from the simulation. Thus, for a high density attack of air threats on ships, this simulation will show bottlenecks in the CCS interfaces caused by the slowness of the UYK 505 processor in executing Battle Management Functions. The resource loading simulation is coded in

SIMSCRIPT and runs on a HP 9000/360 work station. This work is described in Refs. 63-67.

In any potential continuation work involving the Engineering testbed proposed by DMSS 8 (see section 2.6.4), the effect on communication protocols of implementing a knowledge-based STA on multiprocessor COTS platforms must be measured in the SHINPADS bus and at the interfaces of the computers. If the response of a particular computer to data from the command and control system or from another COTS platform is slow, the data accumulation at the computer's interface must not hinder the functioning of the testbed.

3.3.4 Current Work in Situation and Threat Assessment

In the present formulation of STA, a model has been built depending on three real-time air defence functions: threat assessment, defence assessment and kill assessment. The threat assessment and defence assessment functions comprise subfunctions that analyze the geometric proximity of air tracks, estimate the strength of enemy and own force assets and predict the enemy's intentions. The subfunctions of threat assessment, defence assessment and the kill assessment function undergo situation interpretation and situation prediction, i.e., an interpretation is made of what the enemy or neutral forces are currently doing and this is followed by a short term prediction of what they will be doing in the future. A nine function model for STA has been devised in the United Kingdom (see Ref. 68) which includes the three functions mentioned above and additional functions such as mission monitoring. In subsequent work with the ASCACT testbed, implementations of other functions of STA mentioned in Ref. 68 could take place in order to estimate their feasibility for execution in real time.

3.3.4.1 Situation and Threat Assessment in Real Time

Much work has been done to develop non real-time methods and algorithms for STA (see Refs. 69-72). These methods depend on knowledge elicitation procedures using case-based reasoning (see Ref. 69) or on knowledge acquisition techniques based on long term memory, procedural memory and short term memory (see Ref. 70). In order to make these approaches function in real time, an external mechanism such as a meta-level controller can be imposed on the knowledge structure to handle asynchronous inputs and interrupts, organize and schedule tasks using priorities and control the various reasoning mechanisms in order to meet hard task deadlines.

One approach in which an external mechanism is imposed on a non-real time system in order to make it function in real time is the *design-to-time* approach. The design-to-time algorithm provides an approximate solution to a problem for each time interval during which the algorithm acts. After a specific time interval which is chosen by the algorithm designer, the solution returned is exact and complete. A design-to-time approach to a real-time KBS system can be implemented by using a meta-level controller (see Ref. 73).

An alternative real-time approach is to build the artificial intelligence application so that it will be forced to satisfy the real-time requirements of naval STA. The latter approach is called an *anytime* approach to artificial intelligence. This approach to problem solving is characterized by the making of compromises between solution quality and the execution time of the algorithm. The algorithm is designed so that it provides a solution to the problem at anytime and the quality of the solution obtained improves as the algorithm execution time increases. A meta-level controller can be used to implement anytime algorithms for artificial intelligence. The meta-level controller contains algorithms which allocate time intervals during which the STA process will operate on synchronous or asynchronous data received from a suitable process.

The interpretation of the tactical picture will be made in terms of confidence factors or variables involving fuzzy logic. A comparison is made between the predicted tactical situation of the previous time step(s) and the actual interpreted tactical picture of the present time step. In an anytime implementation of STA, the time step over which the comparison is made could be chosen by a meta-level controller (see Fig. 14 for a possible architecture of a real-time STA process). The real-time STA process analyses the tracks to group them into collections of air platforms. An interpretation is made concerning what each group is currently doing (reconnaissance, surveillance, over the horizon targeting) and what it will be doing in the near future (bombing, launching anti-ship missiles, strafing).

The threat assessment function of STA decides which of the tracks in each group of platforms is a threat to the ship and the extent to which it is a threat. It will return an indication in terms of certainty factors, fuzzy logic or probability as to which ships of the

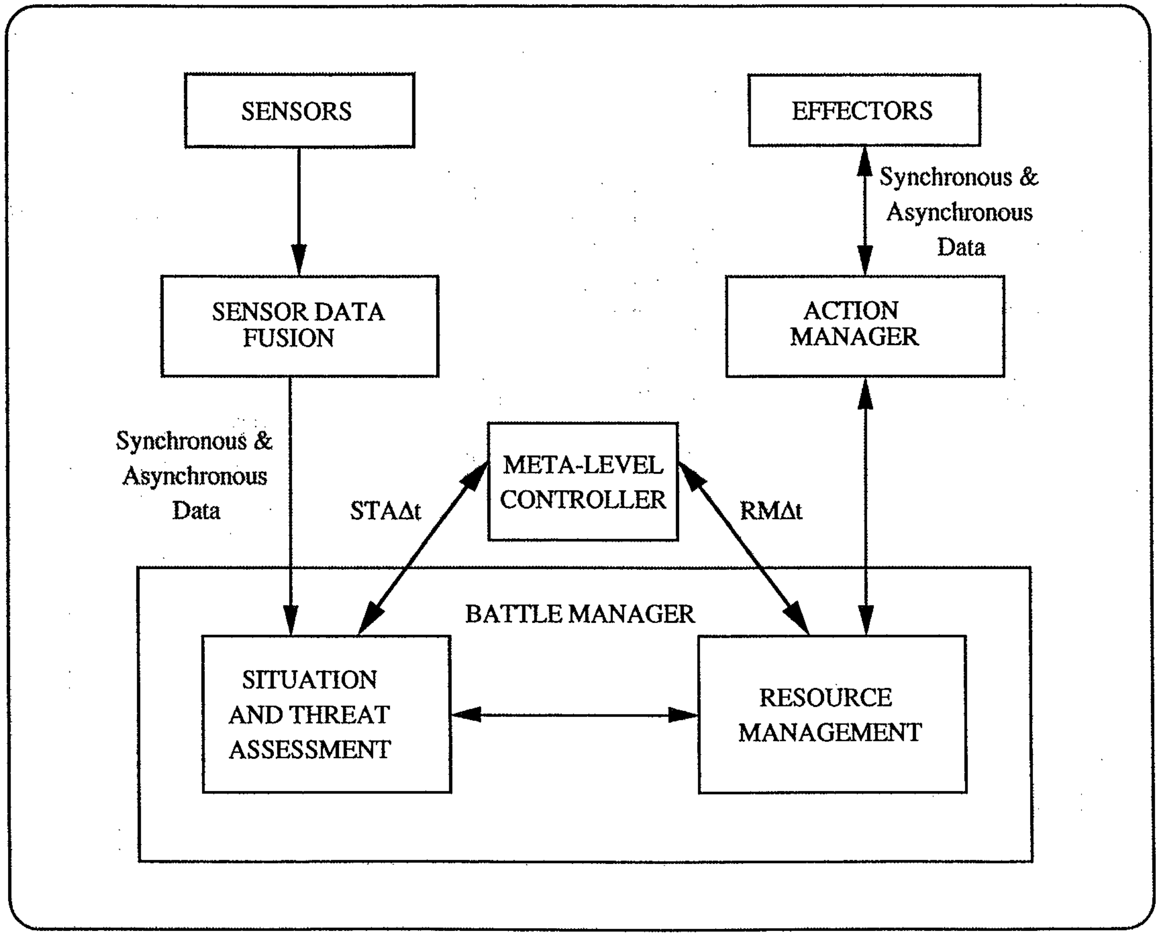

FIGURE 14 - An architecture for the real-time STA and RM processes

convoy are targeted by anti-ship missiles. The extent to which an air track constitutes a threat to a ship is characterized by numerical threat levels although alternative models are currently being studied.

The defence assessment function estimates the state of own force assets and whether these assets can engage the hostile targets at the current time. In STA for multiple ship scenarios, a prediction concerning the best placing of AAW ships is required when the ships are attacked by air threats. In addition, if the AAW commander's air defence plan is not being followed by the other ships of the convoy, the AAWC ship must monitor the AAW situation and alert the ships of the task force to the fact that the plan is not being followed.

The kill assessment function monitors real-time inputs from the weapon systems and threat assessment function to decide whether a threat has been destroyed by a hardkill weapon system or by a softkill weapon system. In the case of softkill assessment, a collaborative effort between the MSDF process and the threat assessment function of the STA process to monitor the trajectory, radar modes and EW characteristics of anti-ship missiles would indicate the degree of success as indicated by confidence factors of softkill weapons used against these threats.

In the ASCACT project, the mission of all naval command and control subsystems including the STA process is primarily local area defence. This means that the STA process resides in a single ship which will be part of a Canadian Forces or NATO task force lead by an AAWC ship. This does not imply that the STA software architecture will be necessarily centralized. The choice of the software architecture for STA will depend on its interactions with the MSDF and RM software units and the results of mapping, scheduling and load balancing studies for a network of distributed workstations executing the integrated MSDF/STA/RM system.

3.3.4.2 Using MUSE for Situation and Threat Assessment

Certain subfunctions of the threat assessment function of naval STA described in section 3.3.4.1 above are being implemented as a sequence of knowledge sources in the real-time knowledge-based shell MUSE. At the present moment, the threat assessment function does situation interpretation, threat evaluation and threat ranking. Work continues at the current time to determine the functionality of these subfunctions, their inputs and outputs, how they will process air track and identity data from the MSDF function and how they will generate output for the resource management function. Ref. 74 which is by no means a complete document on the real-time functional decomposition of the STA process contains some details of its subfunctions and specification.

The current implementation with MUSE is design-to-time in the sense that the knowledge sources are allotted a certain amount of time to calculate their result. A C program acts as an elementary meta-level controller choosing a time interval which is a suitable multiple of the interval between successive updates of the fastest fire-control radar. The MUSE implementation can be made into an anytime application by adding various control units (Poptalk functions) to the existing design-to-time knowledge-based system that 1) partition the air track space 2) partition the number of knowledge sources 3) partition the rulesets within each knowledge source according to specific criteria so that the inferencing can be done within the required time interval. In addition, the control units must increase the size of the track space, the number of knowledge sources that will undergo inferencing and the number of rulesets so that the quality of the STA increases with calculation time.

The threat ranking function of STA which calculates threat levels for fused air tracks has been implemented as a 60 rule forward chaining knowledge source in the MUSE shell. The fused air tracks consist of track position and velocity (radar data), the radar mode of the track (ESM data) and its ESM identity. The subfunction of defence assessment that assesses the state of own force assets has also been implemented as a 25 rule forward chaining knowledge source. Some experiments were conducted to compare the real-time performance of forward chaining and backward chaining inferences in the knowledge source. The experiments consisted of reading vectors of data at one time stamp from an exterior file into the MUSE knowledge source. The knowledge-based implementation of these two subfunctions (threat ranking, state of own force assets) of the STA process is a design-to-time approach. A stimulator has been built in C for producing air tracks from long range radars, medium range radars, fire-control radars, ESM and IFF.

3.4 Resource Management

Effective resource utilization is essential during a military mission. Automated support systems that aid warfare officers in resource management in the time-critical and stressing environment of naval warfare are expected to be part of future requirements for shipboard CCISs. Such systems will need to address the continuous cooperative, synergistic, and efficient utilization of all resources, while providing increased flexibility and functionality for the human operator. To this end, the C2 Division at DREV has initiated an R&D project aimed at developing automated resource management systems (RMSs) for naval combat systems. The purpose of these systems is to help the personnel to optimize the utilization of scarce renewable and non-renewable resources in defence systems, computational systems and communication systems. In the process, they will provide support in and relief from performing complex real-time command and control (C2) functions in a demanding environment. An example is a sensor management system for controlling one or more sensors. One level of functionality in such a system could be provided by an adaptive radar controller for a multi-function radar (MFR) whose radar variables must be managed by the controller in real-time so that it can respond effectively to a changing radar environment, numerous operator commands, and a variety of functions and missions. In this manner, the MFR becomes more flexible and the use of this resource is optimized.

The project is currently addressing three broad real-time resource management issues: first, the design, implementation and testing of adaptive software agents for continuous real-time allocation and scheduling of defence, computational and communication resources in naval battle management systems; second, the enhancement of the effectiveness of these agents by using concurrent computing technology; and third, the embedding of these agents in a real-time control hierarchy for a supportive, autonomous shipboard STA/RM system for single and multiple ships (Ref. 75).

A brief description is given below of the ongoing DREV research in resource management that could form the basis for this prototype implementation in ASCACT.

Our schematic of a generic RMS (Ref. 76) is shown in Fig. 15. The principal input to the RMS is from the STA system. This input, together with human interaction via an operator interface, as required or as response time permits, drives the planning and decision support functions for allocating and scheduling the use of critical resources and coordinating the appropriate action executions via actuator systems. Human interaction can take the form of commands to the RMS and/or requests for support from the RMS. This may entail informing or advising the operator by providing him with action

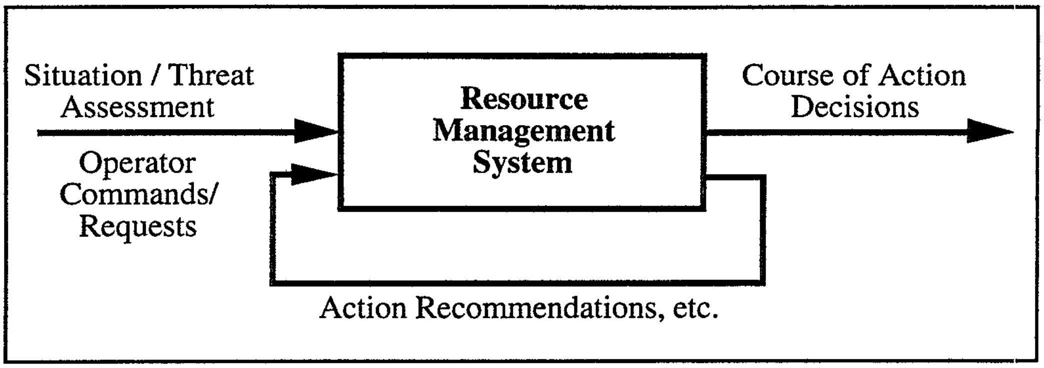

FIGURE 15 - A generic resource management system

recommendations, suggestions, etc., depending on his support requirements and on the division of responsibility between the RMS and the operator (man-machine functional allocation).

Continuously monitoring the effects of actions and recognizing the occurrence of significant events in the world that require new or revised responses closes the loop and leads to adaptive feedback control of the external environment. Planning requires reasoning in time and about time. Internal planning models need to be consistent with the operator's mental states (beliefs, goals, plans, etc.) to ensure that what is planned to achieve is indeed what is desirable to achieve and that the overall effect of the management system is to improve the performance of the operator in achieving his mission. Course of action decisions may be required periodically (e.g., as a result of sensor input) or aperiodically (e.g., due to sporadic interactions with a human operator). Decisions need to be made continuously and executed concurrently, all in real-time. The time available for formulating a response may vary from one planning episode to the next, as a function of hard and soft real-time constraints that depend on situation context. In the combat environment of the AWW, this time is extremely limited, generally ranging from a few minutes to a few seconds. In general, the velocity of significant change in the environment and the nature and extent of the requirement for synchronized interaction with this environment dictate response time in a given situation. At the software development level, this suggests the need to represent and encapsulate temporal behavior (deadlines, types of deadlines, criticality, etc.) so that the RMS can adapt to changes in the environment while reasoning about the necessary tradeoffs between response time and the quality of the response (metareasoning).

Figure 16 presents a simplified representation of our block specification of a two-layered real-time control architecture for the Weapon Engagement Manager (WEM) (Ref. 76). It shows the important functions (represented by blocks) and information flows (represented by arrows) in the architecture. No assumption is made about the specific underlying hardware on which the WEM is to run. This is to allow for hardware availability that may vary dynamically, as well as for dynamic reconfiguration requirements of the software in a combat system for reasons of survivability.

A high-level description of the functions in Fig. 16 is as follows. The deliberative planner uses a planning technique known as simulation-based planning; that is, it computes an effective plan for assigning and scheduling the use of hardkill and softkill weapon systems, and tracking and guidance systems over some time horizon, subject to engagement doctrine and resource availability, by effectively performing a super real-time simulation of the evolution of pertinent features of the combat environment over the plan horizon. The planner provides service in response to the occurrence of an event arising from a significant change in the tactical picture that requires deliberative (re)planning. Recognizing such significant events within temporal constraints is handled by the characterizer, using its internal model of the world and information from the projector and the effector. This model permits nonmonotonic and probabilistic reasoning about change and the effects of actions and their effectiveness over a look-ahead horizon. The projector maintains information corresponding to extrapolations of the state of the world over the forecast horizon. Among other things, projection entails: extrapolating potentially hostile tracks and ship maneuvers; projecting occurrences of events arising from ongoing engagements, previously committed actions, etc., including outcomes of defence actions and threat strikes on own ships; predicting when potentially hostile tracks will be engageable, from which ships and by which weapon systems on such ships, as well as measures of effectiveness of such defensive actions; predicting effects/restrictions associated with obstructions (parts of a ship's structure, chaff clouds, offboard decoys, etc.), environmental conditions, or operational constraints (EMCON, risk of fratricide, etc.) which preclude terminal illumination or threat interception, or which, at least, significantly degrade effectiveness of actions; and predicting positive and negative interactions that result from concurrent use of hardkill and softkill weapon systems. By

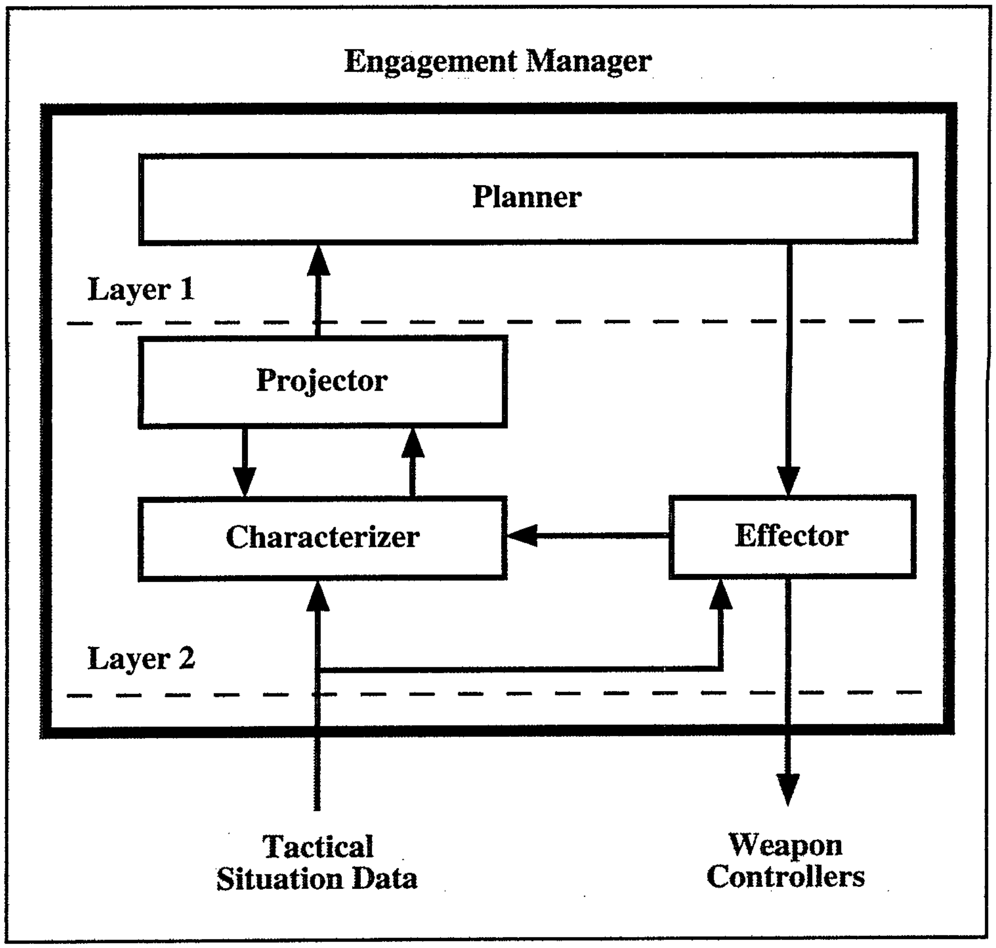

FIGURE 16 - Layered software architecture

communicating with the various weapon controllers, the effector coordinates and directs the execution of plans received from the planner and uses tactical situation fluents to monitor outcomes of defensive actions.

To allow the planner to make tradeoffs in real-time between response time and the quality of its planning, a time-dependent planning technique has been developed. It is based on our notion of almost anytime planning (Ref. 77). The underlying idea is to control the amount of computation involved in plan generation by using a rolling plan horizon whose size is determined at the time of a service call on the deliberative planner. Both contract and interruptible planning variants are being explored. In contract mode, the planner produces a plan within a compute time that is specified at the time of its service call. In interruptible mode, the compute time is not specified and the planner can be interrupted unexpectedly. Such planners therefore allow for a continuum of completion times under time pressure. We are also investigating other approaches to limiting complexity, including using a suite of planners that employ multiple and approximate methods, running in parallel under the supervision of a metalevel controller.

A specific rational agent model for planning surface-to-air missile (SAM) engagements has been developed along with algorithms for its implementation (Refs. 75-81). Planning is utility-driven. This provides a normative basis for rational choice under uncertainty. SAM engagement plans are conditional or contingent in the sense that uncertainty in the outcomes of SAM engagements are explicitly accounted for inside the plan itself by incorporating defence actions and activities to allow reactive response (when feasible) in case of unsuccessful engagements. A plan is therefore closed-loop, with certain of its actions conditional on outcome assessments available to the effector at plan execution time from reactive plan execution monitoring or real-time kill assessment. The advantage of this approach is that it limits the need for deliberative replanning in time-critical situations. Its price, however, is a potentially greater computational load in generating each conditional plan. This is in contrast to an alternative planning approach, based on open-loop or unconditional planning. In this second approach which is also being examined, no consideration is given to planning for contingencies and the fact that knowledge of the outcomes of threat engagement will become available at the time of plan execution is ignored. This has the effect of trading off plan quality for reduced computational complexity of each plan generation; however, more frequent real-time replanning will be required.

Planning SAM engagements over a given planning horizon is computationally intensive. We are therefore investigating the use of distributed and high-performance computing to aid with these computations. The tools being used for this work include:

- DREV's 4K processor CM2a SIMD machine from Thinking Machines Corporation;
- Proteus System, a high-performance parallel architecture simulator that can simulate at instruction level granularity a variety of MIMD multiprocessors; and
- PVM (Parallel Virtual Machine) and SAM, two public domain software frameworks that together allow shared-memory heterogeneous concurrent computing in networked environments

Preliminary static open-loop tests of performance of our MIMD algorithms for the SAM planner (using the Proteus System) indicate that their computational performance scales linearly with the size of the parallel machine used in implementations (Refs. 76, 78-79). This result strongly indicates the feasibility of using advanced deliberative planning techniques in the WEM and points the way ahead for further experimentation involving closed-loop testing on the ASCACT testbed. Experiments are in progress on the CM2a. Preliminary performance testing using PVM and SAM on the C&C network of SPARCstations is only just getting started.

Finally, we mention two other R&D efforts which may impact some of the specifics of an implementation and performance testing of a WEM within the ASCACT testbed:

- an NSERC collaborative R&D grant, involving DREV, Loral Canada, and Université de Montréal (CRT) aimed at further specifying the design and implementation of various resource managers to support real-time decision-making has been awarded; and
- a DIR project has been awarded to Maple Computer Systems aimed at expanding the current potential of simulation technology to permit simulating larger components of a distributed battle management system (e.g., sensor data fusion, situation assessment, and resource management) and evaluation of their real-time performance in both open-loop and closed-loop scenarios.

3.5 MSDF/STA/RM Integration

For historical reasons, previous MSDF, STA and RM R&D activities by members of the Data Fusion and Resource Management Group have approached the problem of satisfying perceived future shipboard CCIS data and information processing requirements in an essentially discrete, bottom-up manner. MSDF has focused on analyzing, developing and evaluating advanced techniques to automatically produce the optimal estimate of the position, kinematic behavior, and identification of all objects surrounding a single ship, mainly through the fusion of data from dissimilar organic sensors, while including non-organic information. STA has been concerned with providing reliable assessments of the situation in which the ship is operating that are important for the successful accomplishment of the mission. Finally, RM has aimed to provide planning and decision support functionality in the CCIS to aid military personnel in the integrated use of critical resources and to manage their coordination in accordance with such decisions. The decision-making referred to here relates to refining and enhancing perception (i.e., sensor management) as well as the management of the ship's hardkill and softkill weapon systems.

Despite the apparent compartmentalization of previous R&D efforts in the group, where the focus of individual efforts has been largely shielded from each other, it is clear that in future shipboard CCISs the MSDF, STA and RM processes will need to work together in an integrated, synergistic manner. Therefore, while MSDF outputs low level perceptions of the tactical picture, STA uses these to provide the higher-level abstractions needed to interpret their meaning and tactical significance. The principal observe-orient-decide-act (O-O-D-A) C2 loop is then closed via RM, thereby providing effective response in support of the mission to significant events in the external, hostile battle environment.

In parallel with continuing efforts within the group to effect refinements and improvements in the individual processes, an important new research focus has therefore emerged recently, aimed at addressing this integration problem in a top-down manner and at evaluating its potential solutions. The end goal of this research is the design of a real-time, semi-automated advisory decision support system, called an MSDF/STA/RM system, that continuously take in data from the ship's sensors and other information sources, build an accurate air tactical picture as quickly as possible, provide the most likely interpretation of the tactical situation, suggest options to defend the ship using the best possible combination of hardkill/softkill weapons or other defensive means (e.g., suggest an optimal sequence of sensor and weapon allocations) and present fused information and decision support analysis results with the opportunity for the Commanding Officer and Above Water Warfare (AWW) team to accept/reject recommended actions/plans in a timely manner, and coordinate and direct execution of these actions/plans.

3.6 Conceptual Framework Study

In collaboration with DMSS 8, DREV is currently looking at different software architectures for the C2 functions of Canadian warships. A necessary requirement for further R&D in this area is to develop an operational conceptual framework, projecting twenty years into the future, that would be used to:

- study the functionality, interrelation and real-time properties of the shipboard C2 functions in preparation for grouping them together into units of operational significance,
- help identify the current areas of deficiencies in the Canadian navy's capabilities and suggest ways in which these deficiencies could be corrected,
- provide a framework supporting the definition and orientation of future maritime R&D projects, and,
- formulate recommendations about cost effective incremental improvements to the capabilities of Canadian ships.

As an initial step toward the development of such a conceptual framework, DMSS 6 has developed and proposed a model, for AAW only, that is illustrated in Fig. 17. The functions of this framework are divided into sensor, C2 and weapon functions. The combat system functions of the NFR 90 are also being considered as a potential model for the development of the required conceptual framework.

In this context, a study entitled: "Conceptual Framework for Studying the Future C&C Requirements of Canadian Warships" has been defined by DREV and DMSS 8. As part of this study, both the DMSS 6 and the NFR 90 models will have to be assessed for completeness; they will then have to be refined and expanded to provide the final product.

Originally, the conceptual framework study was planned as a project in three parts:

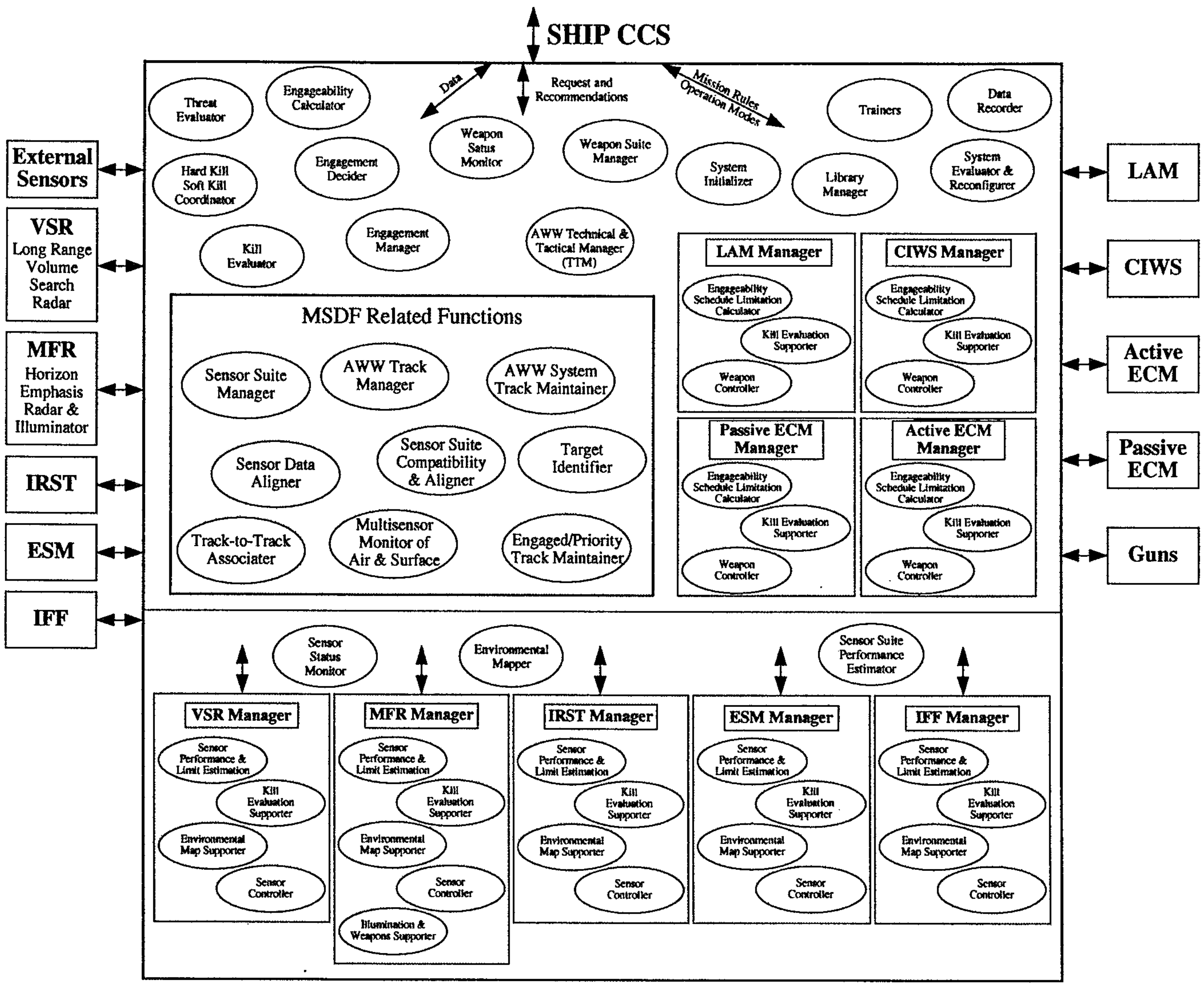

Figure 17 - Conceptual framework initially proposed by DMCS 4

1) definition of the C2 functions of the framework;
2) system integration study designed to map the conceptual framework functions of part 1 into the combat system of the CPF; and,
3) R&D study indicating future research directions which would be desirable for the C2 functions of the conceptual framework.

However, it has been decided to follow a phased approach and to undertake only the first part of the conceptual framework study for the moment. A statement of work (SOW) describing the work which must be done in order to define the C2 functions of the conceptual framework has thus recently been prepared.

The recommendations of such a study defining the inputs and outputs of shipboard C2 functions, their interrelation and their real-time properties can be used to help design the software architecture of MSDF, STA and RM functions for an implementation in a real-time distributed multiprocessor environment such as the ASCACT testbed.

3.7 Collaborative Project with the Industry

There has been a lot of work performed in Canada to investigate various aspects of the MSDF/STA/RM technologies for application on CPF. This work has mostly been done as investigations conducted by DREV and its contractors and collaborators (industry and university), analyzing and demonstrating various MSDF/STA/RM methods for the CPF. While these investigations have addressed a broad range of issues, they do not cover all aspects of an automated CCIS using MSDF/STA/RM techniques and methods in real-time. The research up to now has provided certain pieces of the puzzle (i.e., automated CCIS of the future CPF), while some other pieces still need to be added to complete the picture. The missing pieces represent some MSDF/STA/RM techniques/methods which are not yet fully understood for implementation on CPF, or techniques/methods that are understood, but their real-time implementations have not yet been proven. These could be actualized by performing a number of small and separate R&D activities which then would be fitted into an automated CCIS. However, there are drawbacks to this approach; it would be very difficult to ensure that the complete picture is covered, and that the interfaces between the pieces are compatible. Furthermore each separate task would have to build its own expertise and framework, before actually performing the research, increasing the cost of the overall program in the redundant activities for each task. It would be much more efficient to build the missing pieces into a complete set of proven techniques/methods working in real time (which can be the building blocks of the future automated CCIS for CPF) as part of a complete coordinated project, based on the existing expertise, framework and proof-of-concept software available from the above mentioned work.

To ensure that existing funding, people and facilities are used optimally in such a project, DREV has formed a collaborative partnership with Loral Canada. The top level aim of this ongoing project is to capture and analyze the real-time requirements of a CPF C2 system integrating MSDF, STA and RM, using all information available on the CPF (or future CPF). The R&D activities are jointly managed by Loral and DREV, who meet regularly to evaluate the results of the research and to agree on future directions to be taken.

3.7.1 Simulated-Real-Time Environment (SRTE)

A cornerstone of the proposed methodology for capturing the MSDF/STA/RM system requirements for the ASCACT integration testbed is the design and implementation of a simulated-real-time environment (SRTE) for evaluating concepts, algorithms and architectures for MSDF/STA/RM. In this methodology, all real-time system development and experimentation is conducted on a simulator running on a host (uniprocessor) architecture and the purpose is to capture the functional requirements, temporal behavior and real-time performance of the integrated MSDF/STA/RM system. The simulation engine in the proposed environment will simulate the real-time execution of the MSDF/STA/RM system running on a user configured target hardware architecture, interacting with its user-specified environment. The target could be a single parallel machine or a collection of (heterogeneous) machines connected via a LAN. The simulator will accurately simulate the timing behavior of system code running on the processors of the target. At the same time, it will interleave events associated with computation and communication between threads running on the same processor (machine) or different processors (machines) with events that arise from interactions between MSDF/STA/RM and the external battle world in which it is operating. This environment will permit debugging, testing and nonintrusive performance monitoring of MSDF/STA/RM code. Finally, both open-loop and closed-loop analyses of real-time system behavior will be achievable.

With respect to the ASCACT project, it is expected that the SRTE tool established during the collaborative project could serve multiple goals (conditional to an appropriate match with the tight schedule constraints of the ASCACT project):

1. help in the capture of the baseline MSDF/STA/RM application real-time requirements in support of the development of the SOW for the Project Definition Study (PDS) for the Integration Phase (INTPDS),
2. provide support to DND and the eventual contractor during the conduct of the INTPDS, and,
3. provide support to DND and the eventual contractor during the implementation sub-phase of the Integration Phase.

An ideal design for the SRTE tool would permit, during future application development, switching back and forth between the SRTE and the real-time ASCACT testbed in a manner that requires only recompilation of application code. The idea behind this is to then have SRTE function as a powerful system development environment for the ASCACT testbed.

The collaborative project will conduct an evaluation of various simulation tools for their suitability in implementing the SRTE either on top of them or by their integration into the environment.

4.0 RATIONALE AND FRAMEWORK FOR A REAL-TIME MSDF/STA/RM IMPLEMENTATION

In this chapter, we identify and discuss the main motivation behind DREV's interest in a real-time, integrated MSDF/STA/RM implementation in the ASCACT testbed. The specific factors that motivate DREV's use of this testbed are first discussed with respect to each of the main areas of research taken individually (i.e., MSDF, STA and RM). Then the integration aspect is addressed. Finally, the rationale for the selection of an appropriate MSDF/STA/RM integration framework is presented in the last section of this chapter, along with a first high-level cut at its design.

4.1 Multi-Sensor Data Fusion

As presented in section 3.2, a lot of work on the use of the MSDF technology in a naval context has been conducted by DREV. However, in spite of the broad range of issues that have been studied so far, some very practical and important aspects still need to be given more emphasis.

In particular, the implementation of a real-time MSDF function, taking into account the constraints imposed by the complete C2 system, is a critical aspect of the MSDF domain which has only been given limited consideration so far (Ref. 20). Hence, a major objective of an MSDF development in ASCACT is to explore real-time sensor data fusion concepts (position, identification) that could apply to the current CPF and its potential upgrades, in order to improve its AWW performance against the predicted future threat. Closing the loop with the situation/threat assessment and resource management functions in an integrated CCS is an essential validation step to fully demonstrate and evaluate the benefits of MSDF. ASCACT provides a good opportunity to investigate the interactions between STA, RM and MSDF in a real-time implementation.

The database management and query languages issue and the interaction of the MSDF process/system with its user/operator (i.e., the HCI, operator display management issue) are other aspects which have only been briefly addressed under the MSDF project at DREV (Ref. 21). These issues will be explored in more depth with the ASCACT testbed.

4.2 Situation and Threat Assessment

One purpose of studying naval STA in the ASCACT testbed is to study the real-time performance of artificial intelligence structures for STA when they interface with numerical sensor data fusion algorithms and anytime algorithms for resource management. In the ASCACT testbed, the STA software will be subjected to an approximation of the real-time anti-air warfare environment of the CPF and its performance can be compared with that of data fusion and resource management so that all of these functions respond suitably against a multiple threat air attack. In addition, the data which has been used to test real-time STA algorithms up to the present time has been of a limited nature though reasonably accurate. The ASCACT testbed will be a place to test the real-time performance of STA algorithms with data of a more diverse nature coming from a real-time MSDF process.

Another purpose for using the ASCACT testbed is to study the performance of artificial intelligence (knowledge-based systems, fuzzy expert systems, neural networks and case-based reasoning tools) in real time on multiprocessor architectures. An important objective will be to compare the real-time performance of a multiprocessing system for an AI naval STA process as compared with the real-time performance of a uniprocessor system for the same AI naval STA process and list the advantages and disadvantages of the multiprocessor system as compared with the uniprocessor system. The main reason is to determine the best multiprocessing architecture for a CPF environment. The multiprocessor system will be compared with the uniprocessor system to evaluate how much better it is in terms of satisfying deadlines, responding to interrupts and resetting task priorities. In order to achieve this main objective, a series of sub-objectives will be studied, including the mapping of knowledge bases (fuzzy expert systems, neural networks, hypothesize and test structures) onto processors of the multiprocessor architecture; the scheduling of aperiodic and periodic tasks which are generated by the AI processes residing on these processors. Moreover, an attempt will be made to obtain numerical estimates for the timeliness, responsiveness and graceful degradation of the AI system to real-time data. The testbed and its environment will be used to test algorithms which could increase the speed of the multiprocessing system in the knowledge-based naval STA application.

Another reason for using the ASCACT testbed as a real-time experimental testbed is to evaluate the real-time performance of the naval STA models in a closed loop combat system simulator. It is envisaged that design-to-time and anytime algorithms for the knowledge source STA model described above in section 3.3.4.1 or a modified version of it will be implemented on multiprocessor COTS platforms of the ASCACT testbed. Fuzzy expert systems will be built on the COTS platforms of the testbed to model the adversarial planning function of STA. A comparison will have to be made to assess the benefits of adversarial planning using fuzzy systems for a STA process compared with a knowledge-based system that performs only threat ranking.

The knowledge-based STA process makes use of several new ideas such as tactical situation prediction and the monitoring of defence assessment plans. Further work that could be done in the testbed is to measure the quality of the tactical situation prediction obtained by the knowledge bases as a function of the number of ships and threats in the scenario. Since situation prediction involves hypothesizing a case and then rejecting or accepting this hypothesis, the function will have to store many cases and then find the correct case within the real-time requirements. The testbed will be an ideal place for testing the real-time performance and accuracy of the situation prediction algorithms. A knowledge-based STA module will be built comprising threat assessment, defence assessment and kill assessment functions performing situation interpretation and prediction of the tactical situation within the stringent real-time constraints of anti-air warfare. The quality of the tactical picture produced by the anytime algorithms will be assessed by various measures of performance. The system will be designed to process real-time data coming from the MSDF function and will distinguish peaceful scenarios from hostile ones. The hostile scenarios will be assessed by the threat assessment and defence assessment functions of STA.

The overall performance of the STA module is controlled by a meta-level controller. The ASCACT testbed could be used for investigating the form of the meta-level controller. The options to be considered are: utility functions or knowledge-based systems. Depending on the tactical situation, the meta-level controller will supply one or several time intervals during which the STA module will be required to produce a response. The design of the meta-level controller will be made in order to accommodate the overall real-time requirements of the MSDF/STA/RM process.

The ASCACT testbed has a real-time database capability. Hence an objective for research in the ASCACT testbed will be to study the interaction in real time of these databases with the knowledge-based STA module in multiple aircraft and anti-ship missile scenarios.

4.3 Resource Management

All of the work reviewed in section 3.4 has been performed entirely in-house at DREV. While it has from the outset focused on a range of real-time issues, the lack of a suitable testbed, associated tools and human resources has of necessity restricted concept exploration studies to static open-loop testing of certain time-critical parts of a specific RMS. The objectives of a resource management implementation in the ASCACT testbed have to do therefore with a considerable widening of the focus of the current work to include a broader and more realistic range of real-time implementations leading to a prototype RMS in an integrated MSDF/STA/RM system. In addition, the work will encompass both static open-loop testing and dynamic closed-loop performance evaluations.

The specific RMS to be part of this study is a weapon engagement manager (WEM) in a supportive, autonomous system. The problem is to continuously help a warfare officer decide about the allocation and engagement scheduling of weapons for a single-ship (coordinated engagement) or for a convoy of ships (both coordinated and cooperative engagement) under attack by air and surface threats. The role of the manager is therefore to plan, coordinate and direct in real-time point or local area AWW defence actions involving hardkill and softkill weapon systems to achieve mission goals in response to requests for support or commands from the warfare officer.

In addition to the architectural and algorithmic aspects associated with the design of the manager, it is expected that this work will also study issues related to automated RM as a support and decision aid, including support requirements of the operator, various context-dependent modes for the division of responsibility between the system and the operator, and decision-making protocols for the various modes.

The specific objectives of the work related to a WEM implementation in the ASCACT testbed may be summarized as follows:

- to implement and analyze adaptive techniques for integrating planning, control and coordination of weapon systems and at the same time prototype a decision aid or RMS for the use of these resources;
- to implement and analyze software architectures and associated concepts for integrated real-time resource management in the AWW that aid in designing systems which satisfy both logical and temporal requirements; and
- to implement and analyze sequential and parallel/distributed algorithms for planning and effecting in real-time the coordination of weapon systems in the AWW and to quantitatively demonstrate via both open-loop and closed-loop testing the benefits of distributed and high-performance computing for improving combat system performance.

The end goals of the work are: to establish proof-of-concept; to develop a capability for specifying, implementing, validating, and evaluating real-time system integration concepts to support future shipboard requirements for real-time resource management; and to reduce risk in any potential follow on development stage.

4.4 MSDF/STA/RM Integration

In Section 3.5, we proposed the integration of MSDF, STA and RM in a combined system, which we refer to as the MSDF/STA/RM system, as a major new R&D focus of the group. These processes are naturally interconnected in the O-O-D-A C2 loop; for example, Section 3.5 has hinted at their input/output relationships. However, these and other relationships remain to be more clearly defined and understood.

At a high-level, we know that integration requires optimal use in real-time of available organic and non-organic information to build a coherent tactical picture to support human or automated decision-making and to provide effective response coordination. However, the specifics of this integration have yet to be circumscribed. For example, we have only mentioned the principal O-O-D-A loop, but many subloops involving information flows at different velocities with the man in the loop at a variety of levels and in varying roles are in reality involved. Moreover, both for the sake of the performance of the individual processes and the overall performance of the integrated system, there is the important matter of specifying the temporal dimensions of the system's behaviors. The fact is that integration has to achieved in an environment in which response times are at a premium and the necessity for a variety of synchronized interactions at various points of these loops with the combat environment can require some critical timing constraints on system behavior to be satisfied. In addition, it is likely that such integration will require vastly increased computing capabilities than is present in the current generation of naval surface combatants if satisfactory, predictable and robust real-time behavior of the integrated system is to be achieved. Questions of identifying how much additional computational capability is required and where, as well as the benefits to the C2 system to be derived from such increased capability, are important issues that need to be addressed.

In view of this discussion, it should therefore come as no surprise that some significant challenges for the design of automated tactical CCISs will have to be confronted. A key goal is the development of a methodology for achieving this integration, which, ideally, is independent of the particular weapon and sensor technologies involved and which allows for the incorporation of inevitable advances in computer hardware and software technologies.

Finally, it is important to note that an essential step in establishing this methodology is the development of the ASCACT testbed as a versatile testbed that can serve as a tool for extensive exploratory and empirical analyses and evaluation of theoretical concepts that are fundamentally important to achieving this integration. This testbed will therefore have a major role to play in studying the problems associated with MSDF/STA/RM integration. In addition, it will provide a serious basis for evaluating our past R&D progress and making important tradeoff decisions related to our future efforts in MSDF, STA and RM. For example, for the first time we shall be in a position to start providing well-founded answers to fundamental questions like: what are the individual and collective performances of these processes that can be realistically automated in real-time?; how do we know that our work on theoretical concepts is leading to realizable performance improvements on board the ship and what is their impact (both absolute and relative) on improving mission success?; in short, how do we know we are making progress, and at what cost? While this is clearly an ambitious path to follow, it is an essential and much needed one.

4.5 Preliminary Definition of an Integration Framework

The discussion in Section 4.4 strongly suggests that the selection of an appropriate MSDF/STA/RM integration framework as a basis for subsequently defining a baseline application in the ASCACT testbed is an important issue to be resolved. (The purpose of the baseline application will be to serve as a proof of concept of the ASCACT testbed.) The remainder of this section is therefore devoted to briefly presenting the rationale for the selection of this framework and to describing a first cut at its design. Further details and refinements of this framework will be given in the second document to be delivered for the task.

A number of requirements on the integration framework have been identified. Some general requirements are as follows:

- it should be compatible with an evolutionary approach to system design; in particular, this means that it should be very flexible, easily amenable to extension and updating with upgrades in hardware and software technologies and as DREV's R&D efforts in MSDF, STA and RM mature;
- it should be highly modular to facilitate independent, incremental extension of its subparts, as well as multiple implementations of these subparts both for purposes of experimenting with these subparts and for designing hybrid solutions capable of performing under a variety of temporal and other constraints on behavior;
- it should clarify the identification (design?) of tools to be used as a bridge between specification of the baseline application and its implementation and facilitate the design and implementation of an integrated real-time MSDF/STA/RM system.

Other specific requirements are determined by the purpose of the C2 system and the nature of the problem spectrum that is being addressed by MSDF, STA and RM in the C2 system. The C2 system, which includes both men and machines, exists to aid the Commanding Officer and his team in using the available resources to achieve the mission. Generally speaking, the C2 process is hierarchical. In particular, this means that mission objectives are progressively decomposed into subordinate objectives until a level is reached where individual resources are involved. A variety of levels of abstraction in the C2 problem solving process, types of information processing, timing constraints on this processing, and divisions of responsibility between men and machines are thereby involved. The problem spectrum is identified in Fig. 18 and the portion of the spectrum occupied by each of MSDF, STA and RM is roughly delineated. However, the spectrum for human systems integration with these automated processes is not given here as such important issues remain to be more clearly defined.

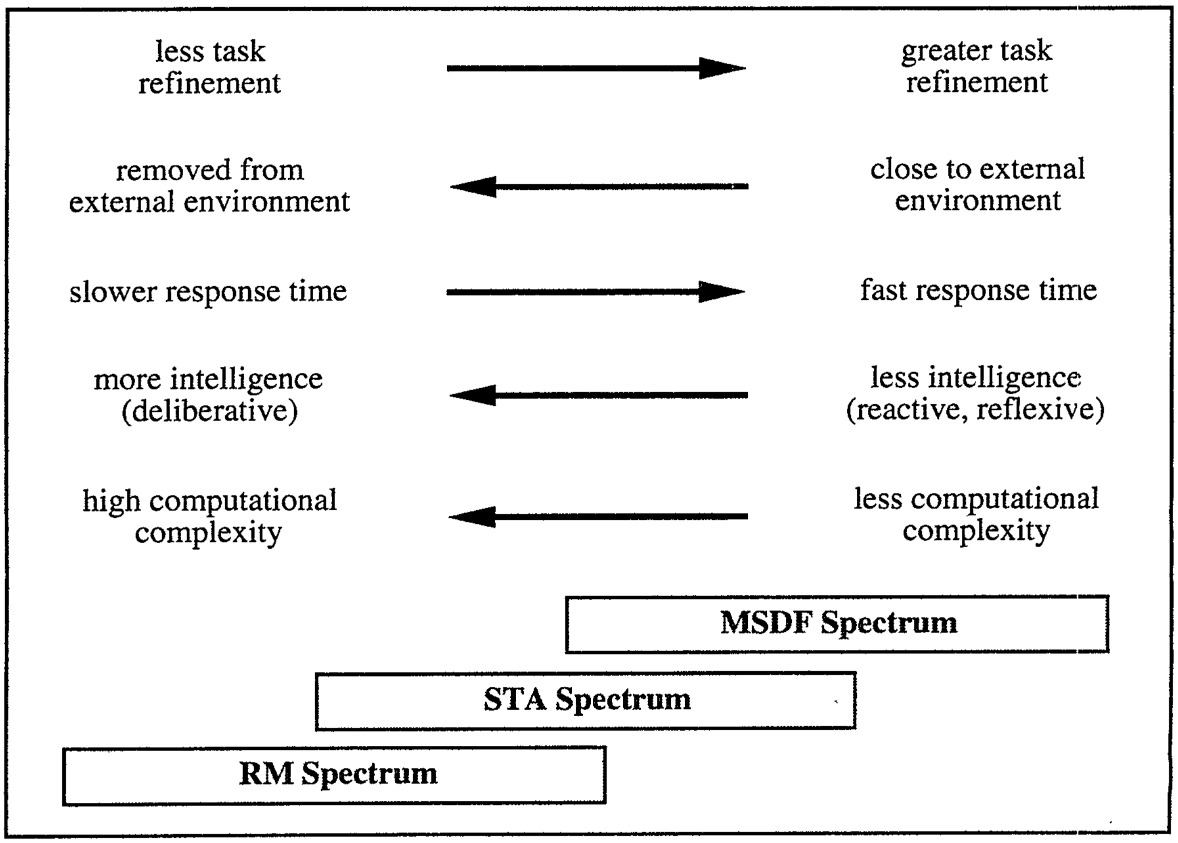

FIGURE 18 - MSDF/STA/RM problem spectrum

In view of these considerations, a layered software architecture appears to offer an attractive basis on which to build a suitable integration framework. A first attempt at specifying this software architecture at a high-level is given in Fig. 19. Layering provides an effective means of responding to the requirements described above. In addition, it promotes the clear separation of design issues from implementation and performance issues. For example, no assumption is made in Fig. 19 on the underlying hardware on

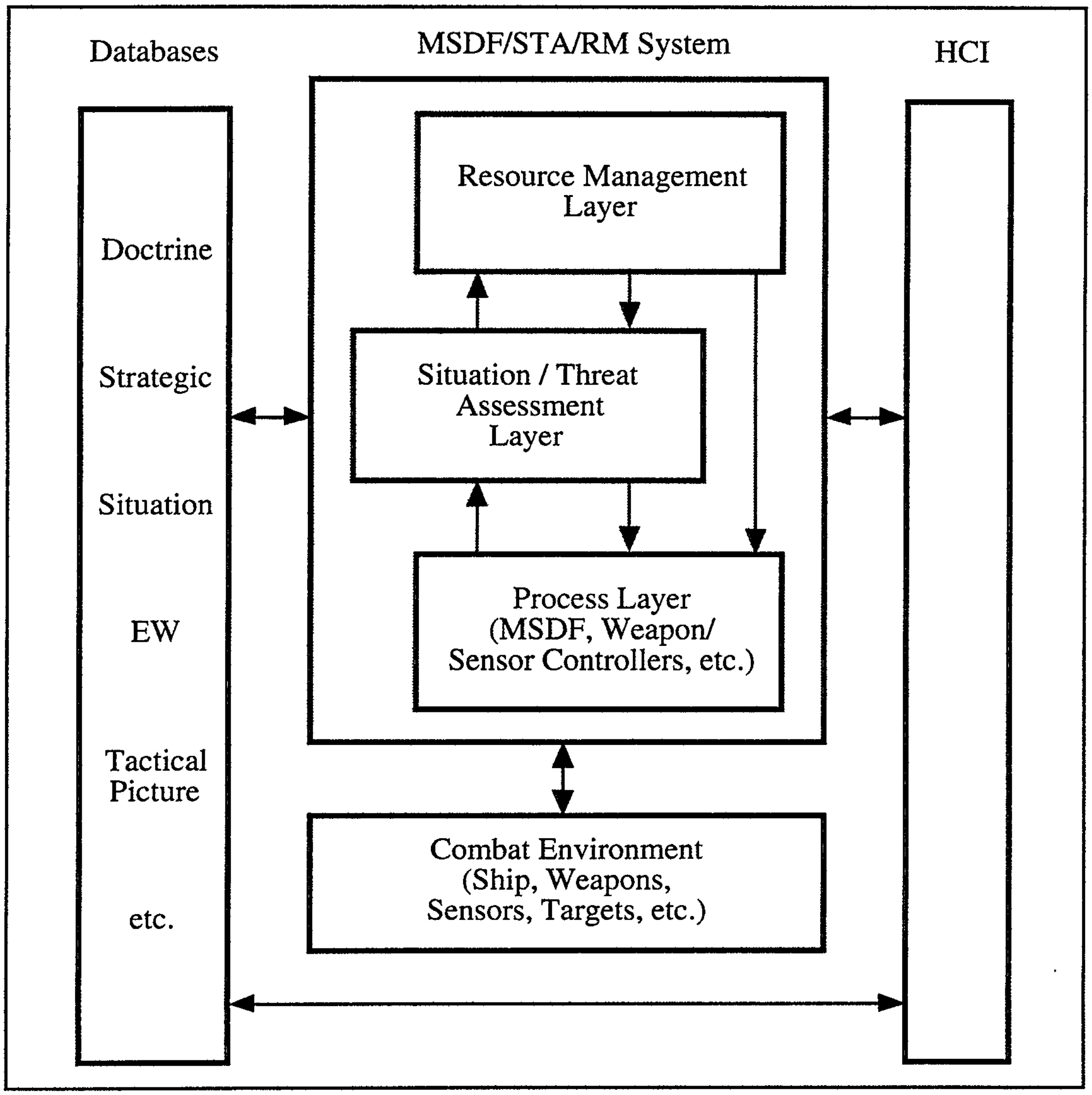

FIGURE 19 - A first cut at a layered architecture for integration

which the various layers are to be implemented and, in fact, several distinct implementations of communication mechanisms may also be needed depending on the specific implementation that is adopted, e.g., uniprocessor or multiprocessor. Typically, lower layers in the architecture will operate rapidly, with high frequency and short delays. The layered software approach is therefore conducive to the development of a variety of layer-specific run-time executives (RTEs), depending on the nature, temporal characteristics and implementation of transformations on the information flows in a layer, and the services required in that layer. Depending on system design, the functionality of an executive may be provided as part of the application in a layer, as part of a real-time kernel, or exist as a separate service sub-layer. These are design choices that will have to be made.

We note that no attempt is made in Fig. 19 to align the databases and the various HCI components in accordance with the layering in MSDF, STA and RM since this requires more careful study. In addition, further work is needed to describe the details of each of the MSDF/STA/RM layers shown there. These and other issues will receive attention in the second document (i.e., "Report #2") to be delivered for the task..

So far, we have addressed the structure of the integration framework. There remains, however, the important issue of the design methodology for achieving this integration. This methodology will be described in "Report #2". We note, however, that it will be founded on a synthesis of many different views of the integrated real-time MSDF/STA/RM system which are needed for its complete specification. To conclude this section, we present five views that will need to be accounted for.

1) Combat Environment: The combat environment includes the ship and its organic and non-organic information sources, weapon systems, and the targets, both friendly and hostile, the physical environment, and the liveware. (Note that in Fig. 19 the liveware accesses the MSDF/STA/RM system via the HCI subsystem.) This view requires an accurate description and analysis of the behavior of the environment, including its temporal aspects.

2) Functional Requirements: This describes the input-output behavior of the various system components in each layer, as well as their hierarchical specification.

3) System Behaviour: This view addresses questions of when, how and why things happen as the MSDF/STA/RM system reacts and changes state over time.

4) Performance Evaluation: The performance objectives of MSDF/STA/RM are specified here and a plan of action for achieving them is prescribed. This plan will undoubtedly be concerned with issues of assigning tasks (statically or dynamically) to the hardware components of the physical ASCACT testbed, their scheduling and potential migration among these components as a (time-dependent) function of system load and time criticality. Achieving this may require extensive performance profiling using high-performance simulation-based technologies to identify performance bottlenecks and system limitations, and to evaluate appropriate tradeoff mechanisms.

5) Hardware/Software: This view describes the underlying structure of the testbed, including its processor components and interconnects and the means of achieving the use of these resources via OSs, compilers and high-level communication mechanisms.

5.0 THE ASCACT INTEGRATION WORKING GROUP

This chapter discusses the ASCACT Integration Working Group (AIWG) that was established by DMSS 8 and DREV in November 1994 to fulfill a requirement jointly identified for a formal information exchange mechanism between the two organizations about R&D issues relevant to ASCACT. The mandate, membership and operations of the group are briefly presented below.

5.1 Mandate of the Group

The main purpose of the AIWG is the preparation of the SOW (based on the completion of the requirements) for the ASCACT Integration Phase Project Definition Study (INTPDS) leading to the implementation of real-time MSDF, STA and RM on the ASCACT integration testbed. The AIWG should enable an information transfer to occur between the main DND contributors to the project. The group utilizes an iterative approach that should lead to a sound development minimizing the risks during the implementation phase. The purpose of the AIWG is also to define DREV's involvement within the INTPDS and the subsequent implementation phase.

The timeline for the completion of the INTPDS SOW has been established as January 1996, with commencement of the INTPDS planned for late March 1996. The estimated timeline for the beginning of the implementation phase is January 1997.

5.2 Membership

The AIWG primarily consists of members from DREV and DMSS 8 with representation, as required, from DSAM, DMSS 6, DREO and other agencies associated with the fields of MSDF, STA, RM and other shipboard CCIS related matters. It is chaired by LCdr E.G. McLean, DMSS 8-8, Project Manager (PM) for ASCACT. The current members of the group are:

Dr.	É. Bossé	DREV/DST Section	
Mr.	R. Carling	DREV/DST Section	
Dr.	B. Chalmers	DREV/DST Section	
Mr.	J.-P. Lachance	DMSS 8-8-2	(Project Engineer ASCACT)
Cdr	D. Parks	DSAM 2	(Project Director (PD) ASCACT)

Mr. J. Roy DREV/DST Section
Mr. U. Seltitz DMSS 8-2

DMSS 6 has been invited to participate in the activities of the group (currently with Mr. A. Beaulieu as their representative) to provide input on how MSDF is to be implemented in the ASCACT testbed.

5.3 Operations

Via monthly meetings, as illustrated in Fig. 20, the AIWG must resolve the ASCACT testbed requirements. More precisely, in collaboration with DMSS and DSAM through an active participation in the AIWG, DREV will identify, capture, analyze and document the requirements for the ASCACT integration testbed in terms of stimulator, measures of performance, environment modeling, data fusion, situation and threat assessment, resource management, processing requirements, etc., in order to generate a highly flexible testbed.

The end result will be a foundation for the generation of the SOW for the Project Definition Study (PDS) for the integration phase. DREV will also assist DMSS-8 in the establishment of this SOW and in the evaluation of the PDS proposals.

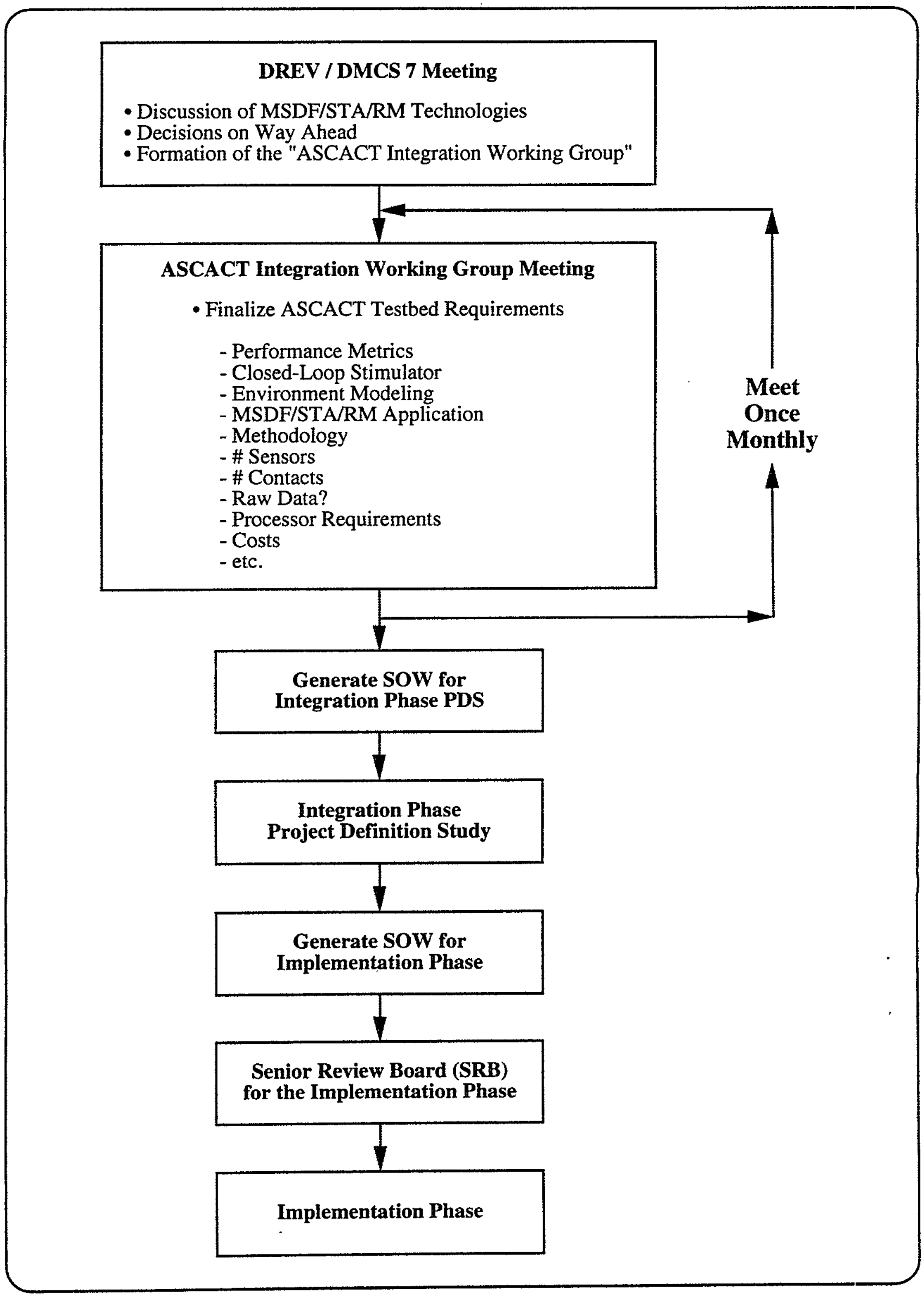

FIGURE 20 - Operations of the ASCACT Integration Working Group (AIWG)

6.0 CONCLUSION

Through an active participation in the ASCACT Integration Working Group (AIWG), the Data Fusion and Resource Management (DFRM) group at DREV is currently providing consulting services in support of the preparation for the Integration Phase of the ASCACT project. Due to the extent of DREV resources required for the successful completion of the ASCACT testbed, a new task has been defined to provide the required support for the project. This task is conducted by the DFRM group with DMSS 8 as the sponsor.

This document is the first of three to be produced by DREV as deliverables for the task. The contents of this document respond to the requirements of Activity 1 as specified in the Task Description Sheet (TDS). In that respect, the R&D work conducted at DREV in the areas of MSDF, STA and RM that can potentially be used in the ASCACT testbed was identified and described and the level of effort to port that technology to ASCACT was also discussed. The baseline information necessary to get a working knowledge of the past, current and future activities relevant to the project was provided. Hence, in addition to the presentation of DREV's R&D work, an overview of the ASCACT project, a discussion of the context in which the project is conducted, and a description of the AIWG mandate and activities were also provided in this document.

The ASCACT project and testbed were described in Chapter 2.0. The aim of the project, along with a description of its main phases, and the DND support for the project were given. Some information about the context in which the ASCACT activity is conducted was also given in this chapter. In particular, the project was identified as a major component of a set of tools and activities relevant to the development and/or acquisition of integrated shipboard C2 systems for the CPF. Given the broad scope of the issues raised in the enhancement activities put forward for the CPF CCIS, it has been quickly recognized by the AIWG that no single tool or activity will be sufficient to provide DND with all the required answers. The R&D environment for the CPF CCIS must rather provide a compatible set of tools and testbeds starting with the DREV testbeds for basic proof-of-concept research, then continuing with the ASCACT testbed for research and development, some combination of ASCACT and a shore-based SHINPADS bus system for advanced development and, the shipboard system for user feedback and trials. Moreover, the R&D process for the CPF CCIS will undoubtedly require several iterations in the proposed tools/activities loop, where the results of one iteration lead to refinements, extensions and improvements in the next iteration. It is also evident that progress will both impact and be impacted by naval requirements (i.e., the customer must be kept involved during this iterative process) and that this interaction may subsequently even help in shaping naval doctrine. As such, this will require work both inside and outside the immediate scope of the ASCACT project.

The integration of the non-organic information, which is deemed as essential to the ASCACT testbed, was also discussed in Chapter 2.0. The ASCACT project (and equivalently its associated integration testbed) has been conceived to address data processing R&D issues relevant to the tactical CCIS of CPFs. Moreover, the emphasis for the first baseline application to be implemented and investigated with the ASCACT testbed is currently given to the management of the organic information for the CPF (i.e., MSDF/STA/RM based on CPF organic resources). However, the ASCACT project team also considers other aspects (e.g., the integration of the non-organic information, the strategic issues) associated with the global C2 architecture put forward for the Forces. For example, R&D for the shipboard CCIS must take into account the issues related to the various CCISs ashore. In terms of the future expansion of the ASCACT testbed, the hooks to evolve from a tactical only system to a system that also operates on strategic information must be identified. The potential input/output requirements for the MSDF/STA/RM baseline application running on the testbed must be identified. In that respect, two major activities that are closely monitored by the ASCACT team in order to ensure that the ASCACT testbed will remain in line with progress made during the CF global C2 architecture evolution were briefly discussed. These are the management of organic and non-organic information in the maritime environment and the national level command and surveillance activities.

The R&D work conducted at DREV in the areas of MSDF, STA and RM was identified and briefly described in Chapter 3.0. The mission of the DFRM research group was first introduced, along with various definitions (i.e., data fusion, etc.) derived and adopted by the DFRM group to establish the scope of its work. The many R&D outcomes resulting from the activities of the group were then summarized and discussed for each research area taken individually, followed by some remarks on the investigation of the MSDF/STA/RM integration issue. The discussion of these R&D results also included some references to current work (in particular, a study for the definition of a conceptual framework for shipboard CCISs and a collaborative project with the industry).

Chapter 3.0 only summarily discussed the level of effort required to port the MSDF/STA/RM technology R&D results from DREV's work to ASCACT. A significant amount of work still remains to be done on identifying which areas of DREV's available results and proposed work should be implemented and further investigated within the initial version of the ASCACT testbed. Recommendations must be made on which areas best meet ASCACT requirements for implementation, while carefully considering the risk of advancing with undeveloped theories and applications. The areas of study should possess high potential for success (i.e., follow a medium risk approach) and be able to be ported to a shipboard application for operator assessment (although the timeline for this port remains to be defined). As much as possible ideally, consideration should also be placed on international work which has been accomplished in these fields to ensure duplication of effort is minimized (i.e., do other countries have algorithms, development models which could be used?). These considerations mentioned above fall beyond the scope of this document and will be addressed in a subsequent document to be delivered for the task.

The main motivations behind a real-time, integrated MSDF/STA/RM implementation in the ASCACT testbed tool were identified and discussed in Chapter 4.0. The specific factors that motivate DREV's use of this tool were first discussed with respect to each of the main areas of research taken individually (i.e., MSDF, STA and RM). Then the integration aspect was addressed. In parallel with continuing efforts within the DFRM group to effect refinements and improvements in the individual MSDF, STA and RM processes, an important new research focus has emerged recently, aimed at addressing the integration problem in a top-down manner and at evaluating its potential solutions. In that respect, a key goal is the development of a methodology for achieving this integration, which, ideally, is independent of the particular weapon and sensor technologies involved and which allows for the incorporation of inevitable advances in computer hardware and software technologies.

An essential step in establishing the methodology mentioned above is the development of the ASCACT testbed as a versatile testbed that can serve as a tool for extensive exploratory and empirical analyses and evaluation of theoretical concepts that are fundamentally important to achieving the MSDF/STA/RM integration. This testbed will therefore have a major role to play in studying the problems associated with MSDF/STA/RM integration. In addition, it will provide a serious basis for evaluating our past R&D progress and for making important tradeoff decisions related to our future efforts in MSDF, STA and RM. For example, we shall be in a position to provide well-founded answers to fundamental questions like: what are the individual and collective performances of these processes that can be realistically automated in real-time?; how do we know that our work on theoretical concepts is leading to realizable performance improvements on board the ship and what is their impact (both absolute and relative) on improving mission success?; in short, how do we know we are making progress, and at what cost? While this is clearly an ambitious path to follow, it is an essential and much needed one.

The selection of an appropriate MSDF/STA/RM integration framework as a basis for subsequently defining a baseline application in the ASCACT testbed is an important issue still to be resolved. The rationale for the selection of this framework was presented in Chapter 4.0, along with a first high-level cut at its design. Further details and refinements of this framework will be given in the second document to be delivered for the task.

The AIWG established by DMSS 8 and DREV to fulfill a requirement jointly identified for a formal information exchange mechanism between the two organizations about R&D issues relevant to ASCACT was finally discussed in Chapter 5.0. The mandate, membership and operations of the group were briefly presented.

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The objective of the ASCACT (Advanced Shipboard Command and Control Technology) project is to improve data processing capability for shipboard Command and Control Information Systems (CCISs) by developing a multiprocessor testbed. The general purpose of the ASCACT testbed is for the integration of high performance Commercial Off-The-Shelf (COTS) products into the shipboard CCIS in order to resolve the envisioned high speed, high throughout, data base intensive applications of the future. The ASCACT testbed will allow investigations to occur on any combination of these requirements. To fulfill the objective of an ongoing task sponsored by the Directorate Maritime Ship Support (DMSS 8), the Defence Research Establishment Valcartier (DREV) is currently providing consulting services in support of the ASCACT project. The content of this document responds to the requirements of Activity 1 of the task. In that respect, the document identifies and describes the R&D work conducted at DREV in the areas of Multi-Sensor Data Fusion (MSDF), Situation and Threat Assessment (STA) and Resource Management (RM) that can potentially be used in the ASCACT testbed. It also discusses the level of effort to port that technology to ASCACT. In addition, an overview of the ASCACT project, a discussion of the context in which the project is conducted, and a description of the ASCACT Integration Working Group mandate and activities are also presented.

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